X-752-72-136

PREPRINT

NASA TM X-65906

FINAL REPORT
NASA BALLOON — AIRCRAFT RANGING, DATA AND VOICE EXPERIMENT

(NASA-TM-X-65906) NASA BALLOON: AIRCRAFT RANGING, DATA AND VOICE EXPERIMENT S. Wishna, et al (NASA) May 1972 69 p CSCL 17G
N72-25601
Unclas
G3/21 30234

S. WISHNA
C. HAMBY
D. REED

MAY 1972

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

69

FINAL REPORT
NASA BALLOON-AIRCRAFT
RANGING, DATA AND VOICE EXPERIMENT

S. Wishna

C. Hamby

D. Reed

MAY 1972

ABSTRACT

During September 1971 at Aire-Sur-l'Adour, France, NASA conducted a series of tests to evaluate, at L-band, the ranging, voice, and data communications concepts proposed for the air traffic control experiment of the Applications Technology Satellite-F. The ground station facilities, balloon platforms and the aircraft were supplied by the European Space Research Organization. One ground simulation and two aircraft flights at low elevation angles were conducted. Even under high interference conditions good performance was obtained for both voice communications and side tone ranging. High bit errors occurred in the data channels resulting in false commands. As a result of the experience gained in operating the equipment in an aircraft environment several recommendations were made for improving the equipment performance.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the European Space Research Organization and in particular to Mr. Dennis Brown, program manager, and his project team without whose help this experiment could not have been conducted. Steve Martin, Bell Aerospace Project Manager, is also to be commended for the field assistance provided NASA during the tests, and for the outstanding effort provided by his project group in getting the experimental equipments to Europe on time.

We also wish to express our gratitude to the Prince Georges County Board of Education (Maryland); to teachers Charles Thompson, Mary Kiefer, and Jack Renner; and to the many volunteer students for helping process the voice tapes. Last but not least we wish to express our thanks to the following personnel of the Space Applications and Technology Directorate: to Mr. Ralph E. Taylor for reviewing the original manuscript and making constructive suggestions; to Mr. William B. Risley for processing the data; and to Mr. Alton E. Jones, Walter K. Allen, Dr. James C. Morakis, Samuel Gubin and George Orr for their encouragement, help and guidance.

TABLE OF CONTENTS

1. INTRODUCTION

An effective air traffic control system must provide voice and data communications as well as surveillance capability. As part of the evolution of such a system, the National Aeronautics and Space Administration (NASA) has made extensive investigations in cooperation with many foreign and domestic agencies and private corporations, e.g., the Department of Transportation (DOT) and the European Space Research Organization (ESRO), to capitalize on the advantages associated with a satellite based system. These studies have led to a comprehensive air traffic control experiment called PLACE (Position Location and Aircraft Communication Equipment). The experiment will begin in 1973 with the Applications Technology Satellite-F (ATS-F) and is designed to further evaluate the PLACE concepts.

During the fall of 1971, ESRO conducted a series of balloon-aircraft tests (reference L)to provide preliminary data defining the performance of a satellite based L-band air traffic control system wherein the satellite was simulated by the balloon. ESRO invited NASA to participate in this test program, and as a result, NASA conducted a series of tests to evaluate some of the air traffic control concepts proposed for the PLACE ATS-F experiment.

The surveillance, data, and voice communication system demonstrated during the balloon-aircraft test program are limited to concept demonstration, the acquisition of limited scientific data, and the preliminary evaluation of technological approaches. Therefore, the experiment described herein should not be considered as a NASA recommendation of any specific air traffic control system.

The specific objectives of the experiment were:

- Provide a preliminary evaluation of the PLACE ATC concept prior to ATS-F launch
- Demonstrate the concepts of continuous and time-division multiplex two-way tracking of aircraft by comparing

experimentally acquired ranging data with radar-determined trajectories of the aircraft.

- Evaluate duplex, Narrow Band, Frequency Modulation (NBFM) voice channels
- Evaluate duplex data channels
- Demonstrate aircraft command and control utilizing the data channel as envisioned for the PLACE experiment
- Obtain operational experience with the PLACE transceiver in an aircraft environment
- Develop techniques for coordination of airborne and ground facilities
- Evaluate test procedures which determine system performance
- Collect sample data similar to that for the PLACE experiment

Directed toward these objectives, this report presents the results of the aircraft-balloon experiment.

2. SUMMARY AND CONCLUSIONS

All experimental objectives of the NASA/ESRO balloon-aircraft experiment conducted during September of 1971 were attained. Furthermore, as a direct result of this experiment, several modifications have been incorporated into the equipment that should significantly enhance the PLACE ATS-F experiment.

2.1 Experimental Results

Essentially, the objectives of the NASA/ESRO balloon-aircraft experiment fall into two categories. First, four basic ATC functions to be performed by the PLACE equipment were to be evaluated. These are (1) high rate (1200 bps) data, (2) side tone ranging for aircraft surveillance, (3) voice communication, and, (4) low rate (600 bps) data to control multiple access and provide commands. The second objective was to gain operational experience using PLACE hardware in an ATC test environment.

High Rage (1200 bps) Data

The performance of the 1200 bps data channel was evaluated by means of the bit errors accummulated in the received data from a PN data transmission during the experiment. Specifically, distributions of bit errors were time correlated with carrier-to-noise density values. These correlations, then, provided a basis for comparison with the theoretical performance of this channel. The result of these comparisons clearly indicate the high rate data channel format must be designed to be less susceptible to interference, if bit error rates less than 10^{-3} to 10^{-4} are to be realized.

Tone Ranging

The precision and accuracy of the PLACE side tone ranging channel were evaluated by a direct comparison of experimentally determined side tone range with precision radar tracking data. These comparisons show excellent performance as evidenced by precision of a few hundreds of meters even during those time periods when considerable interference was evident in other experimental data.

Voice Communication

Both simplex and duplex operation of the voice channel were accomplished during several flight periods. Under all circumstances including periods of significant interference, excellent communications (in the context of ATC requirements) were maintained. This performance was verified by the excellent intelligibility scores obtained from the test words transmitted over the voice channel and recorded on-board the aircraft.

A minimum mean intelligibility of 62% was obtained during the most severe interference while mean intelligibilities on the order of 95% were obtained for strong signal, non-interference conditions. Of the words listeners failed to identify, few were actually missing. Because of its large dynamic range, the NBFM voice channel maintained lock even under severe fading conditions.

Command and Control

The command and aircraft interrogation control was provided by a 600 bps data channel. Although a simple parity check is utilized in this channel to inhibit command/control errors, three such errors did occur during a period of approximately one hour. This frequency of error suggests a need for more sophisticated coding.

Interference

The experiment serves to emphasize the need for carefully monitoring the Radio-Frequency Interference (RFI) environment. The downlink L-band spectrum was monitored at the ground station during all of the flights and considerable interference was intermittently present. Because of the lack of measurement facilities neither the source or level of interferences could be fixed with any degree of confidence. Most of the interference is believed to have originated in the UHF band suggesting for any future balloon flights that this frequency band be avoided for the ground station-balloon link.

2.2 PLACE Equipment Modifications

As a direct result of the balloon-aircraft experiment, several modifications have been incorporated into the PLACE equipment. These should measureably improve the performance of the PLACE equipment during the ATS-F experiment.

AGC Modifications

An important result of the balloon aircraft experiment was the indicated presence of rapid changes in carrier-to-noise ratio. To improve the performance of the AGC, the time constant of the AGC has been shortened from one second to 10 milliseconds.

Loss of Lock and Search

Another aspect of rapid carrier-to-noise fluctuation is the possibility of short lived loss-of-lock. During the experiment, temporary loss-of-lock in the data channels resulted in an immediate entry of the equipment into a two-minute cycle search mode. To eliminate this conditions and thereby reduce susceptance to these transients, a ten second delay has been added after loss-of-lock before entry into the search mode. Additionally, the duration of the search period has been reduced from two minutes to 45 seconds.

PSK Modulation

The occurrence of loss-of-lock frequently resulted in significant data errors, because PSK reacquisition occurred in the wrong sense. The sense correction capability of the equipment did not function rapidly enough to alleviate this problem under low signal-to-noise conditions. To eliminate this condition the PSK modulation system has been changed to a differentially coherent phase shift keying (DCPSK) system. This will limit errors resulting from reacquisition transients to no more than one bit.

Operational Alterations

As a result of operational experience, three further alterations have been made. First, a manual override has been installed in the equipment to permit disablement of automatic search. Second, frequent loss-of-lock occurred during the experiment because of signal transients created by discrete step attenuators. These have, therefore, been replaced with continuously variable controls, Voice and data channel switching controls were changed from knob to pointer types. The last alteration was implemented to improve readability of equipment control positions.

In conclusion, it should be noted that only one minor equipment failure occurred during the experimental period of nearly two weeks. This was a malfunctioning of the power amplifier monitoring circuitry.

3. EXPERIMENT DESCRIPTION

The major five subsystems employed in the experiment were:

- Ground station
- Balloon platform
- Radar tracking station
- Aircraft
- Data processing center

The ground station was co-located with the balloon launch facility at Aire-sur-l'Adour, France and contained the equipment to: (1) generate and transmit all of the necessary data, voice, ranging and command signals, (2) receive and record the return ranging, data and voice signals, (3) monitor balloon transmissions, and (4) receive telemetry data from the balloon.

The balloon platform contained a telemetry link, a radar beacon, and a transponder system. The telemetry link provided balloon power output, temperature and altitude information. The radar beacon provided an enhanced signal return level to the radar. The duplex transponder received UHF signals from the ground station and retransmitted them to the aircraft on L-band, also L-band signals received from the aircraft were converted to UHF and retransmitted to the ground station.

Precision radars, European versions of the FPS-16, were located at Biscarrasse and Hourton, France and tracked the aircraft and balloon during the experiment. These provided digital printouts of aircraft and balloon positions as functions of time.

The aircraft utilized the breadboard model transceiver built for the ATS-F experiment and modified for this program. This transceiver received modulated L-band carriers (ranging and low rate data, high rate data, voice) and demodulated these carriers to produce range tones, voice and data. Output range tones and aircraft—generated voice and data were modulated onto three L-band carriers for transmission to the balloon.

The data processing was accomplished at NASA's Goddard Space Flight Center at Greenbelt, Maryland.

The ranging, data, and voice system is designed to service 250 aircraft by means of time division multiple access. The ground station continuously transmits a 600-bps data stream and range tones, on a low-rate data and surveillance carrier. The 600-bps data contain a series of 8-bit words (with one bit parity) that activates the transceiver logic and internal circuits, selects the time slot for transmission, selects the number of transmissions per frame, and provides voice, data, and emergency channel status indication. To minimize command and control errors, the aircraft transceiver will decode only the low-rate data during the epoch slot, the 10 status slots, and the assigned transceiver slot. The duration of each time slot is 200 msec.

High-rate data channel and voice channel access will (for the PLACE ATS-F experiment) be upon request, with immediate access capability for emergencies. A voice and high-rate data transmission is sent from the interrogated aircraft simultaneously with the ranging and low-rate data. However, the balloon-aircraft experiment used only one ranging and low-rate data channel, one voice channel, and one high-rate data channel.

The high-rate data are generated at a 1,200 bps rate,and differentially coherent phase shift key (DCPSK) modulate a carrier. During the experiment, a pseudo-random code data transmission was used on this channel to determine bit error statistics.

An adaptive narrowband frequency modulation (ANBFM) technique was used for the duplex voice communications. This technique achieves good quality voice reception under low-carrier-to-noise conditions by employing optimized voice processing of both input and output speech and by using a unique adaptive demodulation concept (reduces demodulator bandwidth as carrier-to-noise decreases). The system achieves a 95% modified rhyme test (MRT) voice intelligibility at a carrier-to-noise power density level of 46 dB-Hz, but will exhibit thresholding at extremely low carrier-to-noise levels. To eliminate this thresholding effect, the ANBFM for PLACE was designed to give an 85% MRT word intelligibility at a carrier-to-noise level of 46 dB-Hz. The elimination of thresholding is considered extremely important if the voice system is subjected to severe fading, since this will minimize the number of complete dropouts.

The transmission spectrum is shown in Figure 3-1. Except for the difference in carrier and subcarrier frequencies, this spectrum is identical for all links. The transmitted signal consists of three carriers: F_{c1}, F_{c2}, and F_{c3}; F_{c1} contains the ranging and low-rate data information, F_{c2} contains the high rate data information, and F_{c3} contains the voice transmission. The ranging function is provided by two individual ranging tones (8575 Hz and 7350 Hz), double sideband amplitude modulated onto F_{c1}. The low-rate data are generated at a 600-bps rate and phase-shift-key (PSK) modulated onto a quadrature component of the same carrier F_{c1}. Sufficient carrier power is reinserted to enable carrier lockon at the transceiver. Table 3-1 presents the frequency assignments of the transmitted carriers for each link of the experiment.

Table 3-2 summarizes the link calculations for the balloon-to-aircraft and aircraft-to-balloon links. The critical link with respect to power limitations was the balloon-aircraft link. The ground-to-balloon links were not power limited, primarily because of the lower path loss of the UHF transmission and the use of a high-gain antenna at the ground station. The aircraft-to-balloon link had approximately 17 dB more transmitter power than the balloon-to-aircraft link. The values used for the link parameters were nominal worst case; e.g., the minimum anticipated antenna gains were used and the path loss was computed for the maximum anticipated slant range of 240 statute miles. Table 3-2 shows that for an experimental system a total power density requirement of 49 dB-Hz (voice: 46 dB-Hz; High-rate data: 42.8 dB-Hz; and low-rate data and range tones: 42.0 dB-Hz) could be achieved. These levels correspond to anticipated satellite air traffic control requirements.

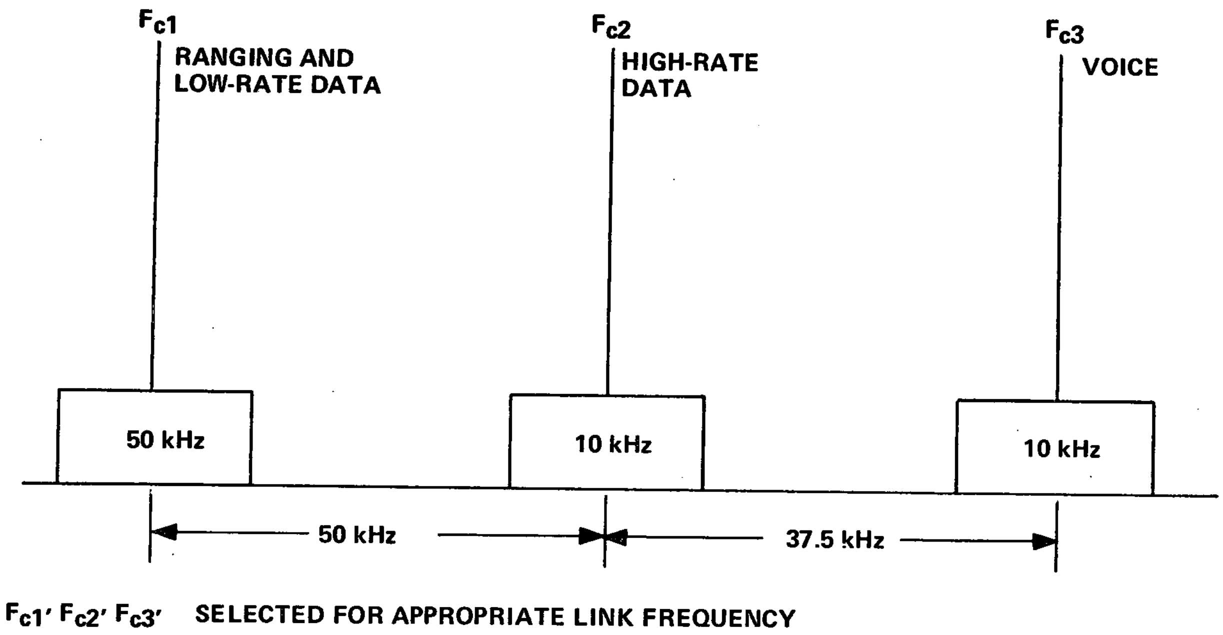


FIGURE 3-1. SPECTRUM

TABLE 3-1

FREQUENCY ALLOCATION

Link	F_{C1} MHz	F_{C2} MHz	F_{C3} MHz
Ground-to-balloon	444.1250	444.0750 444.0000 443.9250	444.0375 443.9625 443.8875
Balloon-to-aircraft	1550.3550	1550.4050 1550.4800 1550.5550	1550.4425 1550.5175 1550.5925
Aircraft-to-balloon	1651.3750	1651.4250 1651.5000 1651.5750	1651.4625 1651.5375 1651.6125
Balloon-to-ground	400.7750	400.7250 400.6500 400.5750	400.6875 400.6125 400.5375

TABLE 3-2

Balloon-to-Aircraft and Aircraft-to-Balloon Link Calculations

Item	Balloon to Aircraft	Aircraft to Balloon	Units
<u>Transmitter</u>			
Power amplifier output	0	17.0	dBw
Cable-diplexer losses	-3.5	-2.0	dB
Antenna gain	+2.0	+4.0	dB
Effective radiated power	-1.5	+19.0	dBw
<u>Path loss</u>	-149.8	-150.2	dB
Fading	-1.0	-1.0	dB
<u>Receiver</u>			
Antenna gain	+4.0	+2.0	dB
Cable-diplexer losses	-2.0	-3.5	dB
Carrier power	-150.3	-133.7	dBw
Thermal noise	-204.0	-204.0	dBw-Hz
Noise figure	+5.0	+5.0	dB
Noise power density	-199.0	-199.0	dBw-Hz
Carrier-to-noise power density	+48.7	+65.3	dB-Hz
<u>System requirement</u>			
Voice channel carrier-to-noise power density	46	46.0	dB-hz
High-rate data channel carrier-to-noise power density	42	42.0	dB-Hz
Low-rate data and range tones channel carrier-to-noise power density	42	42.0	dB-Hz
Total carrier-to-noise power density	48.9	48.9	dB-Hz
Margin	-0.2	+16.4	dB

3.1 Balloon Experiment Equipment

The NASA/ESRO Balloon experiment was designed to make maximum use of existing PLACE equipments and designs as well as available ESRO ground, balloon and aircraft equipment. Figure 3-2, the system block diagram, shows within the dashed lines the NASA equipments that were located in the ground station and the aircraft. Table 3-3 contains a list of the equipments used, including a summary of equipment functions and identification of NASA and ESRO supplied items.

3.1.1 Ground Station

The NASA ground station was located in the ESRO/ESTEC (European Space Research and Technology Center) ground station at Aire-Sur-l'Adour, France. The ground station employed two switchable UHF antennas for communicating with the balloon, one antenna covering elevation angles from the zenith to 45^{o} and the other covering angles from 45^{o} downward. The higher angle coverage was provided by a fixed mounted Archimedes spiral with a nominal gain of 7 dB. The low angle antenna was a four-unit corner reflector with a nominal gain of 18 dB, fixed in elevation but movable in azimuth. These antennas were used for both transmit and receive by employing a diplexer between the antennas and the ground station power amplifier and receiver.

The UHF receiver was a NEMS Clark 1037C with a crystal-controlled RFT 102A tuner head. The receiver 30 MHz intermediate frequency was converted to 70 MHz as an input to the ground modem. Another channel of the same converter was used to provide 444 MHz to the power amplifier from the 60 MHz output of the ground modem. The ground station power amplifier, operating Class C, produced an output power level of 15W from the 10 mw, 444 MHz input signal.

The modem units employed in this experiment were essentially PLACE equipments with minor modifications in channel frequency spacing.

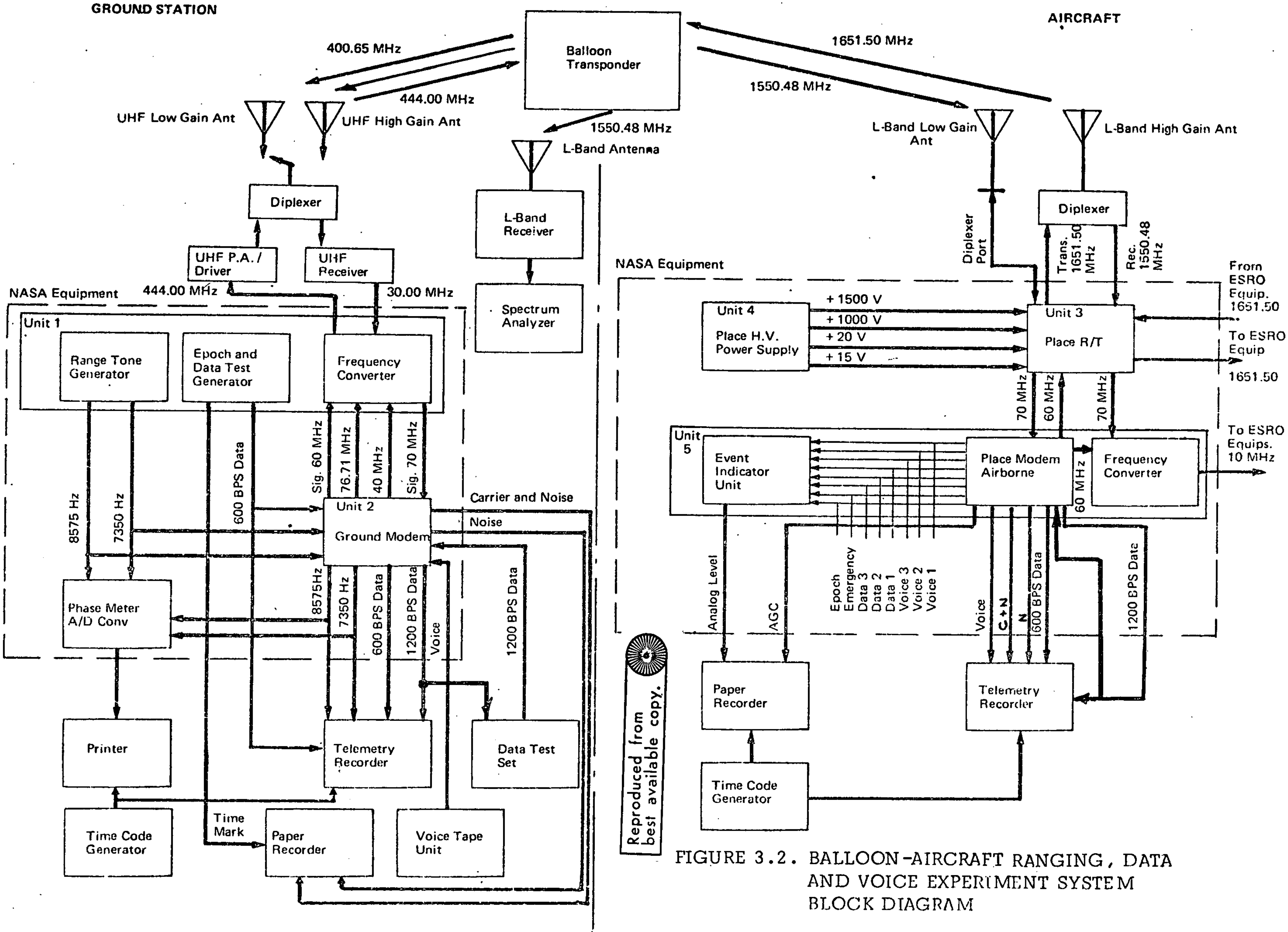


FIGURE 3.2. BALLOON-AIRCRAFT RANGING, DATA AND VOICE EXPERIMENT SYSTEM BLOCK DIAGRAM

TABLE 3-3

EQUIPMENT LIST

BALLOON—AIRCRAFT RANGING, DATA AND VOICE EXPERIMENT

Location	Item	Source	Type/Model	Function
Ground Station	UHF Low Gain Antenna	ESRO		Transmit/Receive Antenna - 4 unit corner
	UHF High Gain Antenna	ESRO		Transmit/Receive Antenna - Archimedes Spiral
	Diplexer	ESRO		Transmit/Receive Channel Separation
	UHF Power Amplifier	ESRO		Class C Power Amplification
	UHF Driver Amplifier	ESRO	HP 230 A	Linear Amplifier
	Frequency Converter	NASA	Bell Model No.____	Converts transmit 60 MHz to 444 MHz and receive 30 MHz to 70 MHz
	Range Tone Generator	NASA	Bell Model No.____	Generates 8575 Hz and 7350 Hz tones
	Epoch and Data Test Generator	NASA	Bell Model No.____	600 bps command and control, 1200 bps, test signal, 1 minute time marker
	Ground Modem	NASA	Bell Model No.____	Demodulates voice, data, and range tones, modulates voice, data, and range tones and converts to 60 MHz
	Phase Meter	NASA	Dranetz Model No. 202A	Measures the phase angle of the received range tones relative to the transmitted tones
	A/D Converter	NASA	HP 5245L, HP 5265A	Converts analog phase angle reading to BCD readout
	Printer	ESRO	HP 5050B	Angle readout of range tone phase shift
	Telemetry Recorder	ESRO	Phillips Analog 7	Record on separate channels received 8575 Hz tone, received 7350 Hz tone, received 600 bps, received 1200 bps, transmitted 600 bps, time code data
	Data Test Set	ESRO	Fredrick Model 600	Generate PN sequences
	Paper Recorder	ESRO	Brush MK 260	Provide analog carrier plus noise and analog noise record
	Time Code Generator	ESRO	Datum Model 9310	Supply serial and BCD readout of clock
	L-Band Receiver	ESRO	Nems Clark 1037G RF Head RFT1040 Modified	Reception of balloon L-band transmission
	UHF Receiver	ESRO	Nems Clark 1037G RF Head RFT102A	Reception of balloon UHF transmission
	L-Band Antenna	NASA	Polarad CA-L	Receive Antenna
	Spectrum Analyzer	ESRO		Adjust power levels and monitor balloon L-band transmission
	Voice Tape Unit	ESRO	Sony TC 366	Play voice tapes into system
	Microphone/Headset	NASA	TELEXCS-61	Voice communications
Aircraft	L-Band Low Gain Antenna	ESRO	Boeing	Transmit Receive Antenna
	L-Band High Gain Antenna	ESRO	Dioscures	Transmit Receive Antenna
	PLACE R/T Unit	NASA	Bell No.____	Receives and transmits in L-band, outputs and inputs at IF. A low power L-band interface is provided.
	PLACE H.V. Power Supply	NASA	Bell No.____	Provides D.C. voltages to R/T unit
	PLACE Airborne Modem	NASA	Bell No.____	Identical to ground station modem except for a 600 bps decoder and activating circuitry
	Frequency Converter	NASA	Bell No.____	Converts 70 MHz IF to 10 MHz IF
	Event Indicator Unit	NASA	Bell No.____	Outputs analog voltage as a function of the number of input events
	Telemetry Recorder	ESRO	Phillips Analog 7	Record on separate channels received voice, received 600 bps, bit error count, time code, carrier plus noise, and noise
	Paper Recorder	ESRO	Brush MK 220	Record output of event indicator, and AGC
	Time Code Generator	ESRO	EECO Model 1125A	Supply serial time readout
	Microphone/Headset	NASA	TELEX CS-61	Voice Communications
Balloon	Balloon Package	ESRO		Consists of the following principle subsystems - transponder, antenna systems, radar beacon, altimeter, balloon telemetry system, and power supply.
Radar Facility		ESRO		Provide aircraft and balloon azimuth and elevation position data.

The ground modem, consisting of a modulator section and a demodulator section, was identical to the aircraft modem except for the lack of the décoder and activation circuitry. The modulator section consists of the narrowband FM voice modulator, DCPSK high rate data modulator, and a low-rate data PSK modulator which has a reinstated carrier in phase quadrature with the range tones. The modulator outputs are summed and the composite a signal frequency translated to 60 MHz. The modem circuit provides control for (1) selecting one of three data channels (2) selecting one of three voice channels and, (3) adjusting the output power level of each modulator.

The inputs to the ground modem consist of two range tones, low-rate data, high-rate data and voice. The range tones are generated continuously by means of a range tone generator which consists of two oscillaotrs at 8575 Hz and 7350 Hz, respectively.

The low-rate data, which also performs the command and control function, is generated at 600 bps by the Epoch and Data Test Generator and provides:

- An epoch sync signal generated each minute,
- Aircraft address, slot position and rate of interrogation,
- Status signals on the use of the three voice channels, the high-rate data channels and emergency,
- Transmission control of the aircraft transceiver.

The Epoch and Data Test Generator provide a coded 24-bit phrase comprising three 8-bit words at selected times relative to a fixed epoch code. The 24-bit code is set manually by 24 switches during normal operation; however, in this experiment 10 of the command and control sequences were wired to a 10-position stepping switch. The stepping switch operated at one step per minute to transmit automatically a new command/control function to the aircraft.

The high-rate data input (1,200 bps) was obtained from a Frederick 600 Data Test Set providing 2047 bits per frame of pseudo-random code. The voice was obtained by playing back on a commercial quality tape recorder a tape containing Modified Rhyme Test words, Phonetically Balanced words, Speech Communication Index Meter (SCIM) signals, and typical air traffic control messages.

The phase shifts of the received range tones were measured by a phase meter, the Dranatz Sampling Vector Computer System Series 202. The references for these measurements were the tones generated by the Range Tone Generator. The phase meter output, a voltage analog of phase angle, was converted to BCD and recorded using the HP 5050B Digital Recorder. Also, time was recorded to the nearest tenth of a second as provided by the time code generator in the ground station.

The telemetry recorder, a Phillips Analog 7, was used to record the Epoch and Data Test Generator 600 bps output, NASA 36-bit serial code from the time code generator, the ground modem demodulated range tones, low-rate data and high-rate data. A strip-chart recorder was used to record the voltage analogs of carrier plus noise and noise from the ground modem.

The ground station also employed an L-band receiver and a spectrum analyzer to monitor the balloon transmissions. This permitted ground station personnel to set the relative power levels of the ranging, data and voice channels by adjusting the modulator drives in the ground modem. Ground station personnel also used this equipment to monitor the spectral purity of the L-band signal received by the aircraft.

3.1.2 Balloon

The balloon and associated equipment were supplied by ESRO. The balloon equipment consisted of the transponder (see Figure 3-3 block diagram), a vertically polarized UHF antenna, a right-hand circularly polarized L-band antenna, a telemetry transmitter and a primary power source.

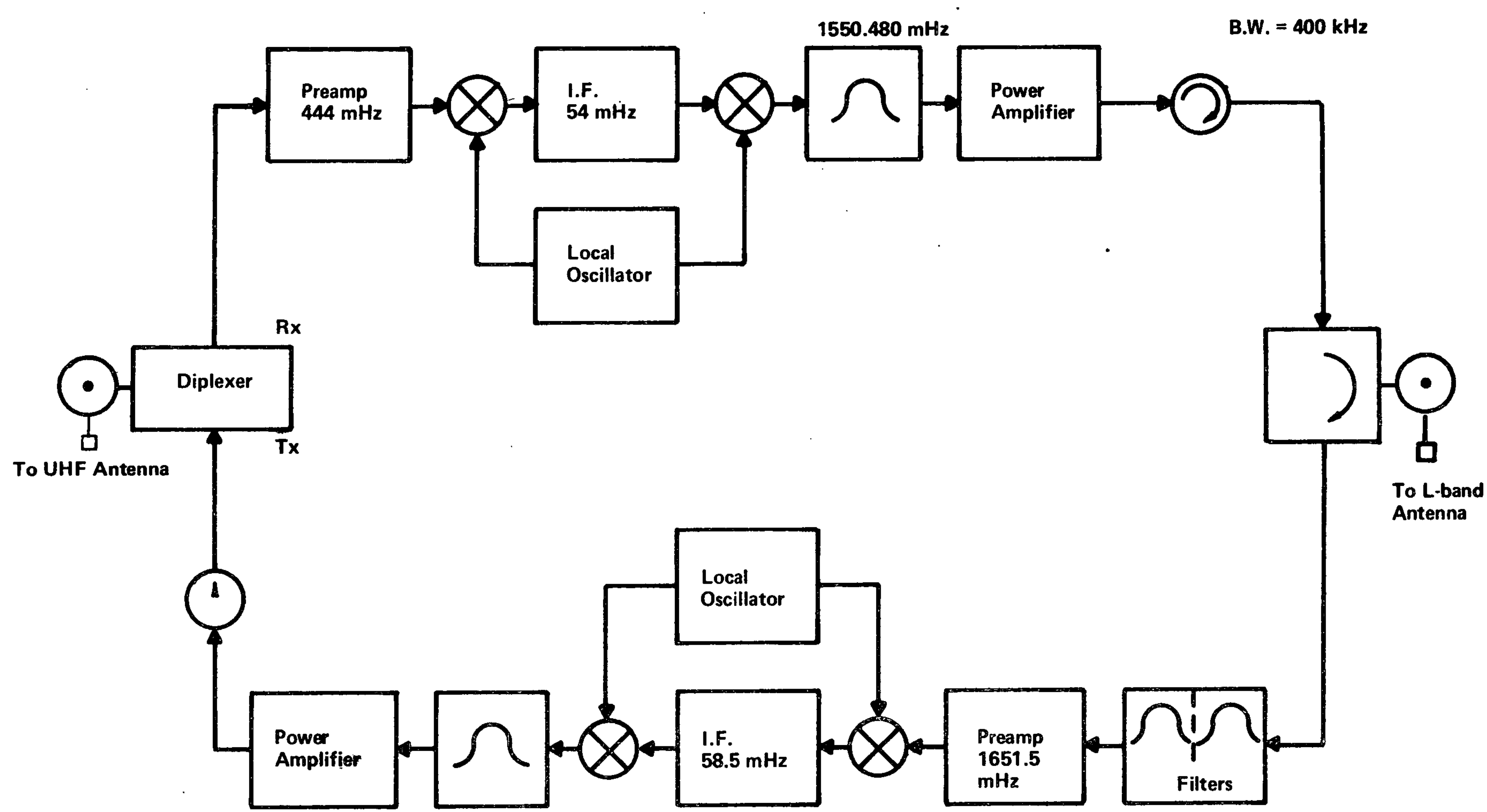


FIGURE 3-3. BALLOON EQUIPMENT

3.1.3 Aircraft

The aircraft employed both medium gain and high gain L-band antennas. The medium-gain antenna, manufactured by the Diamond Company, is a slotted, cross-dipole having a nominal gain of 5 dB. This antenna was flush mounted on one side of the aircraft near the tail assembly. The high gain antenna, manufactured by Elecma of France, is a fixed-array with a nominal 10 dB gain. The Elecma antenna is built as two switchable sections located in the front of the aircraft, with one section facing upward to the right and the other facing upward to the left.

The aircraft transceiver used in this experiment was the breadboard model built for the ATS-PLACE experiment with minor modifications to provide compatibility with the balloon transponder frequencies. The breadboard transceiver consists of three separate units: receive/transmit (R/T), modem and high-voltage power supply. Figure 3-4 is a block diagram of this transceiver.

The R/T unit consists of an L-band diplexer, receiver, down-converter, up-converter and power amplifier. The incoming 1550.48 MHz signal from the antenna is channeled to the receiver input port by the diplexer. The diplexer is bypassed when using the high gain antenna. The receiver down-converter amplifies the received signal and converts it to a 70 MHz intermediate frequency which is then fed to the modem unit. A 60 MHz modulated signal from the modem unit is delivered to the up-converter power amplifier which converts this signal to a 1650.50 MHz L-band signal. The L-band signal is delivered to the antenna through the diplexer.

The High Voltage Power Supply provides all voltages necessary for the R/T unit. The modem contains its own internal power supply.

The Modem Unit in the aircraft is identical to the ground station modem except for the addition of the decoder and activation circuitry. The 70 MHz IF from the R/T unit is demodulated by three demodulators; the range tone/low-rate data demodulator, the high-rate data demodulator, and the voice

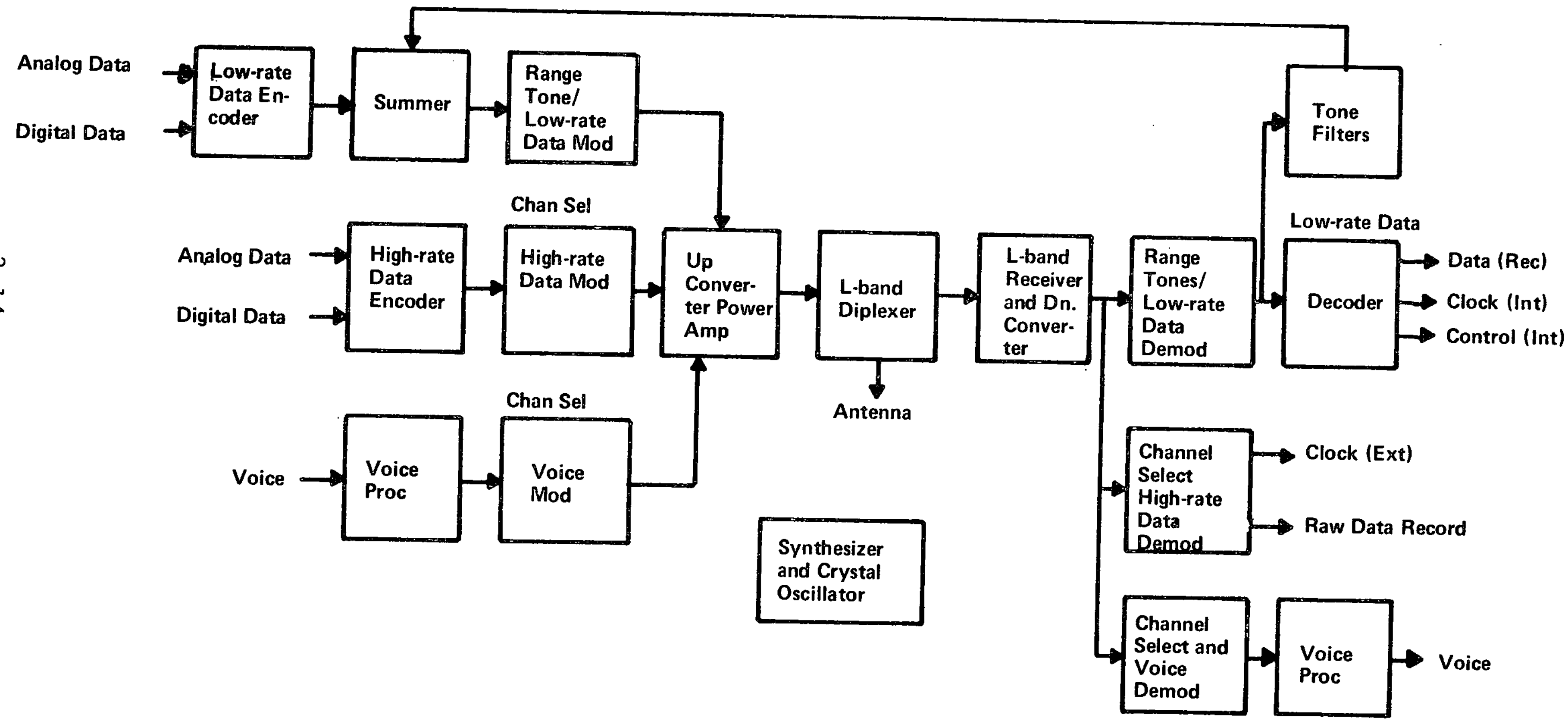


FIGURE 3-4. PLACE EXPERIMENT TRANSCEIVER

demodulator. The demodulated low-rate data and tones are separated and the low-rate data delivered to the modem decoder which provides internal control and event indicator activation.

Modem outputs provided are baseband low-rate data, high-rate data, tones and voice. These outputs are recorded on-board the aircraft. For this experiment they are also delivered to the modem unit modulators. The high-rate data modulator and voice modulator can each transmit on any one of three selectable carrier frequencies. The modulator outputs are summed and up-converted to 60 MHz for delivery to the R/T Unit. During this experiment only simplex data and voice channel evaluations were conducted because of space restrictions on-board the aircraft, precluding full duplex operations.

The decoder decodes the low-rate data from which it identifies the aircraft address, synchronizes the system internal clock and shifts into an appropriate register the assigned time slot. When the clock time coincides with the time stored in the register, the aircraft automatically transmits for 200 msec the range tones and low-rate data. During 10 specified 200 msec slots per minute, the aircraft receives voice channel; data and emergency status information. The decoder provides seven outputs indicating the status of; the three voice channels, the three high-rate data channels and emergency. For this test, to minimize recorder channel utilization, all seven outputs were summed in the event indicator. This voltage sum was then recorded on one channel of the paper recorder and indicates the number of executed commands.

The 60 MHz IF of the R/T unit was converted to 10 MHz to provide the necessary interface with ESRO equipment. A Frederick 600 N data test set was not used on-board the aircraft for bit error measurements because of space limitations on-board the aircraft. The high-rate data was recorded and retransmitted. The time code generator provided a time reference for coordinating the recorded data.

The Phillips Analog 7 telemetry recorder was used to record voice, low-rate data, high-rate data, carrier plus noise analog, noise analog, and NASA time code. A strip-chart recorder was employed to record the received signal AGC and the event indicator output voltage.

More detailed descriptions of the PLACE equipments used in this experiment are available in references (A), (B), and (C). A description of the modification made to the PLACE units used in this experiment may be obtained from reference (D).

3.2 Test Program

The experiment test plan, reference (E), consisted of three test phases:

- Equipment checkout at the manufacturers plant
- Pre-flight tests at the ground station at Aire-Sur-l'Adour, France, and
- Flight tests involving voice communications, data transmission, CW and gated range tones.

3.2.1 Equipment Checkout

The equipment checkout was made to insure that all equipments supplied for the experiment were operating within specifications. The pre-flight test served to verify that equipment installation and calibration had been properly performed, while the flight operations were used to collect the necessary data to meet experiment requirements.

The equipment checkout consisted of individual equipment tests plus an RF loop back-to-back test. Figures 3.5 and 3.6 define these tests which confirmed adherence to design specifications.

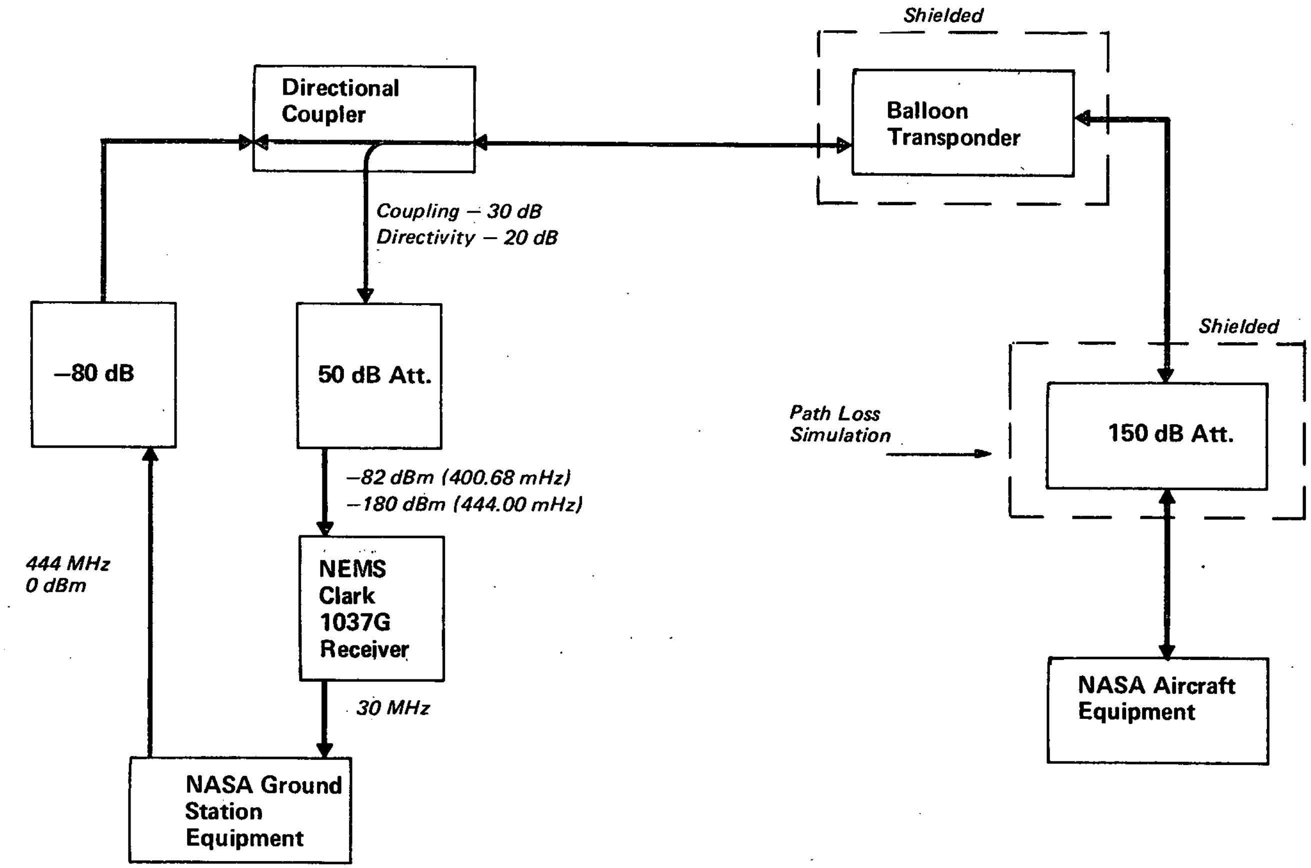
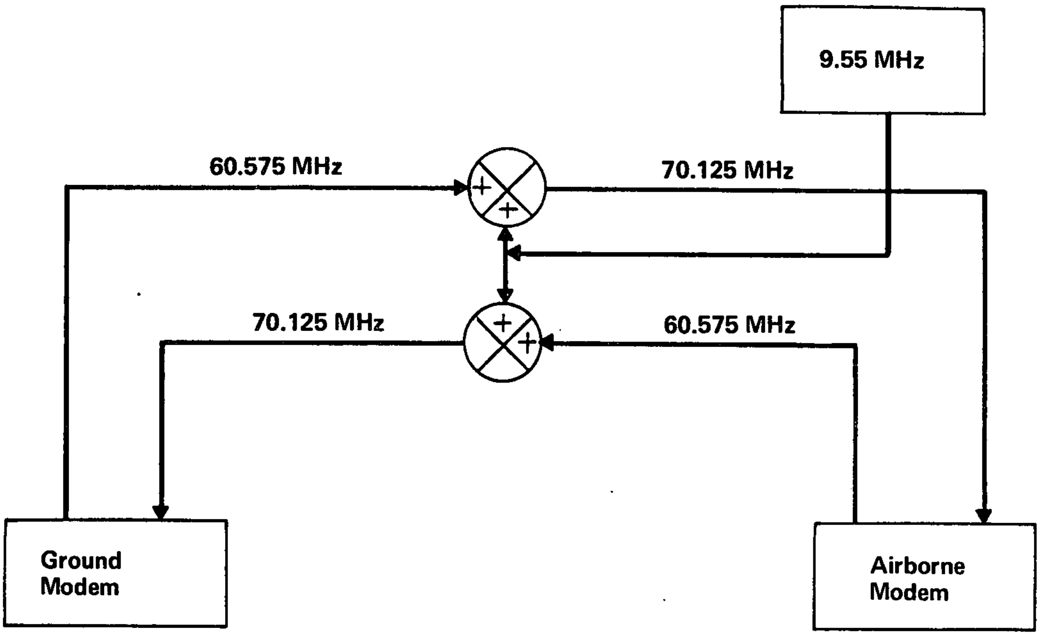


FIGURE 3-5. RF LOOP INTEGRATION TESTING



Test Sequence

1. Calibrate S+N and N Test Signals.
2. Verify Continuous Operation.
3. Verify Multiple Access Performance.

FIGURE 3-6. PRE-FLIGHT EQUIPMENT TESTS

3.2.2 Pre-Flight Tests

The pre-flight tests were conducted on 9 September 1971 utilizing: the ground station at Aire Sure l'Adour, France; an aircraft parked at Pau Airport; and the balloon transponder located on a near-by mountain top, known as Pic-Du-Midi. This is the highest accessible point having line-of-sight visibility for both the airport and the ground station, the elevation angle being about 5 degrees from the ground station. Data recorded during this test were:

- Analog of carrier power level plus noise
- Analog of noise power
- Range tone signals
- Phase angle of returned range tone signals
- Bit error count on 1200 bps data channel.

3.2.3 In-Flight Experiment

Figure 3-7 illustrates the flight test configuration. During each segment of a flight test the aircraft was flown on a nearly circular course, at a constant elevation angle relative to the balloon. Tests were planned for angles of 5, 10, 15 and 20 degrees; however, because of logistic constraints, tests were run only at 5 and 10 degrees.

Tests initially planned consisted of a CW ranging and a multiple-access period with each period containing four 45-minute segments, one at each elevation angle. Figures 3-8 and 3-9 show the operational time plots associated with the two test periods. Each flight segment of each period was to utilize both the low gain and high gain antenna for approximately equal time intervals.

Allowing time for aircraft manuevering between flight segments, it was estimated that a complete test could be concluded in four hours. Accordingly, three flights of appropriate duration were scheduled to insure the collection of sufficient data. Adverse weather conditions forced the cancellation of one

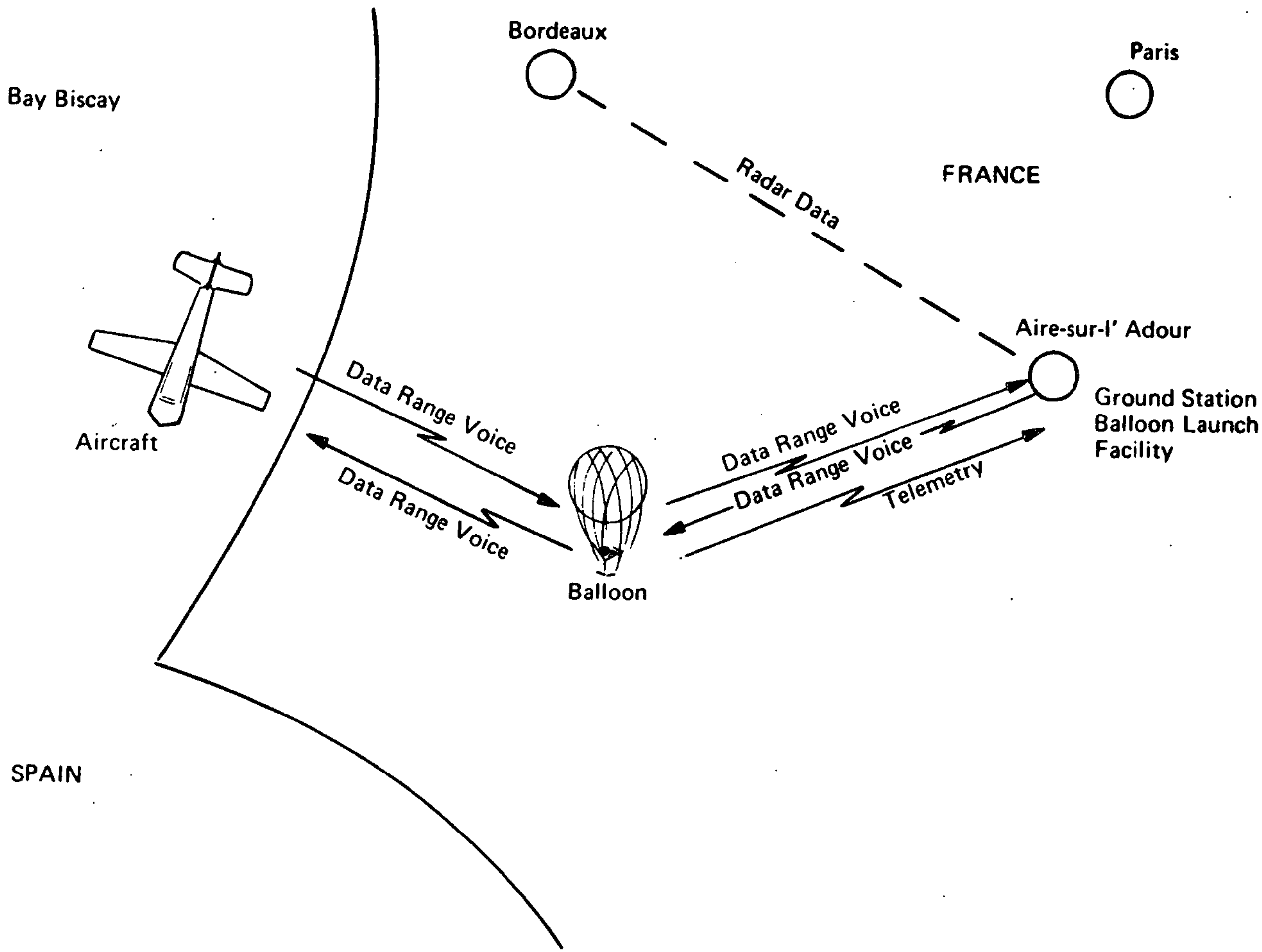


Figure 3- 7. Pictorial Test Facilities—Balloon-Aircraft Ranging, Data, And Voice Experiment System

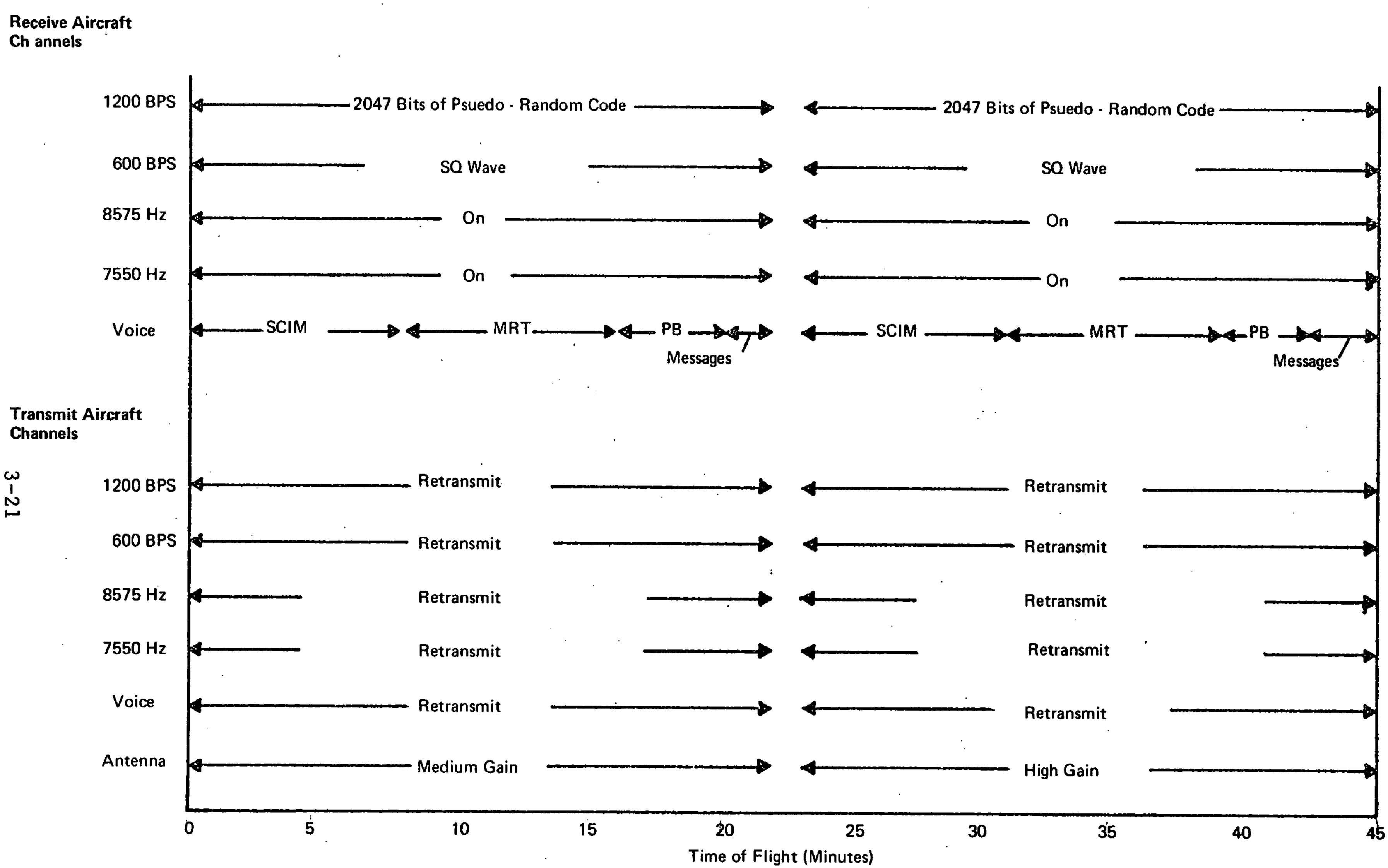


FIGURE 3-8. PHASE I 45-MINUTE FLIGHT SEGMENT

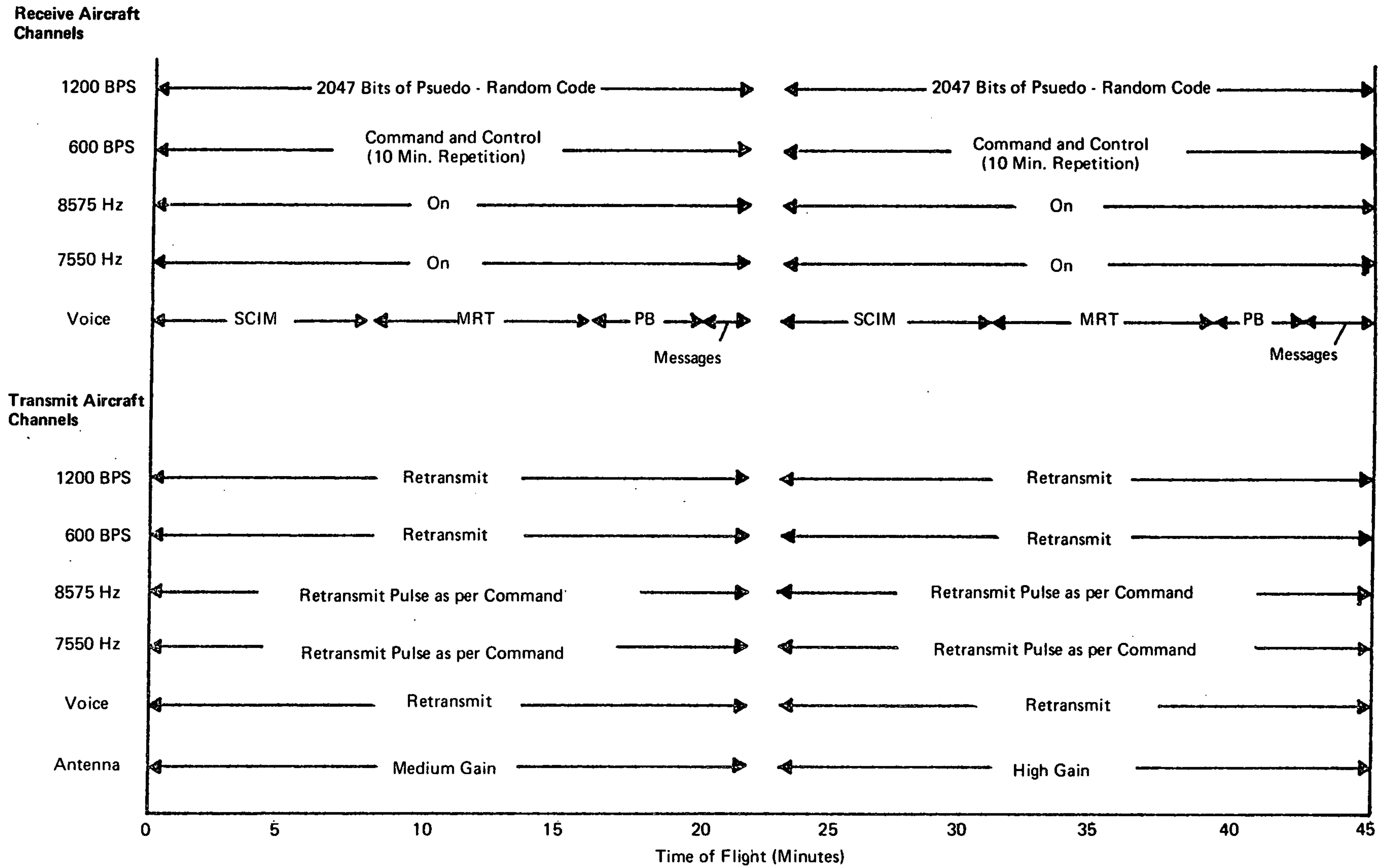


FIGURE 3-9. PHASE II 45-MINUTE FLIGHT SEGMENT

entire flight, and severly restricted the time available on another. Consequently, the actual flight tests were limited to:

- A flight of approximately 195 minutes on 13-14 September 1971, this flight being supported by ground radar coverage of both the aircraft and the balloon.
- A flight of about 20 minutes on 17 September 1971. No radar coverage was provided for this flight.

3.3 Experimental Data

The flight of 13-14 September 1971 consisted of five separate segments, one at an elevation angle of approximately 10 degrees and four at approximately 6 degrees. These five flight segments totaled 128 minutes of flight time. The remainder of the flight time was in transit to and from the test area and aircraft manuevering between segments. Figure 3-10 shows the ground tracks of the aircraft for each of the five flight segments together with the track of the balloon during the same time period.

Although a total of 128 minutes of planned test conditions occurred, only 56 minutes of tone ranging and data were acquired. This difference is due to repeated loss of lock for these channels during all but the first two flight segments. However, voice communications maintained lock more consistantly and were recorded for a total of 120 minutes.

Figure 3-11 is a time-line presentation of the data collected. The two top lines indicate periods of time for the five flight segments shown in Figure 3-10. The antennas employed during these segments are also noted as well as the approximate elevation angle of the balloon above the aircraft horizon during the different segments. The third line presents the intervals of time during which the two different range-tone frequencies were transmitted and received. As noted, these tones were transmitted in two modes. One of

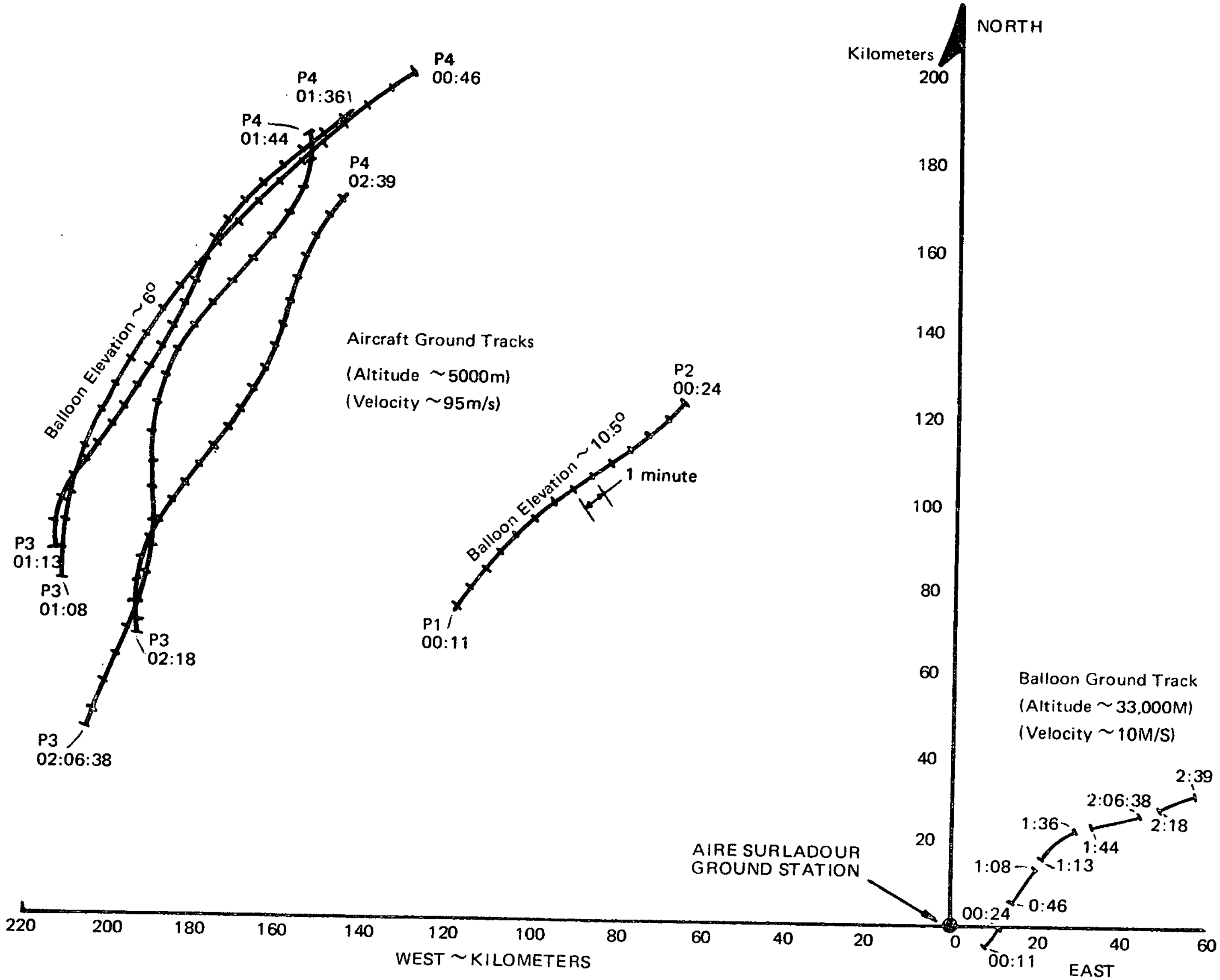


FIGURE 3-10. AIRCRAFT AND BALLOON GROUND TRACKS

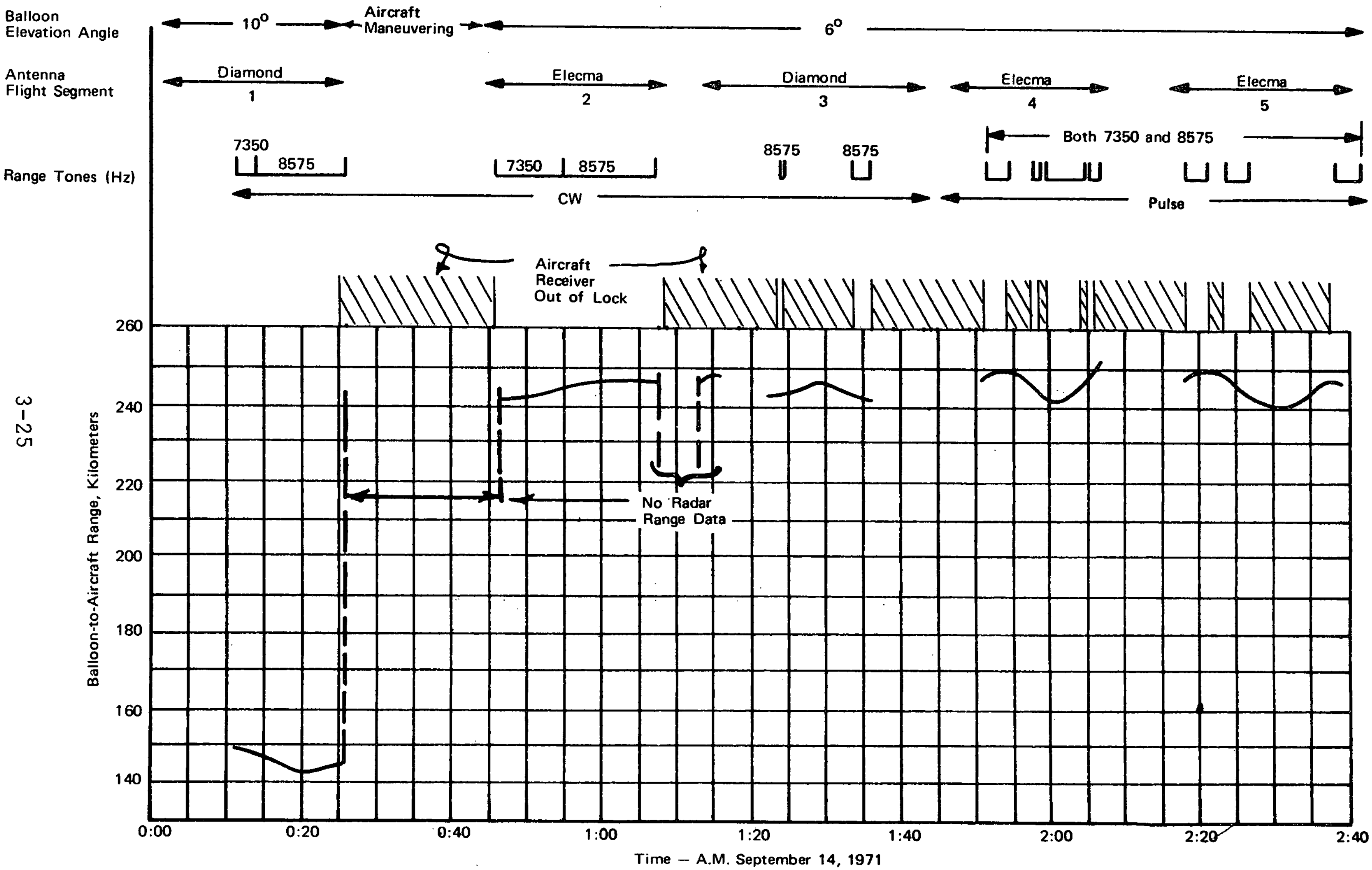


FIGURE 3-11. DATA ACQUISITION TIME LINE

these was a CW mode wherein the tone was continuously transmitted for several minutes at a time. The other mode was a pulse mode wherein the tones were transmitted for 200 millisecond intervals.

The lower part of Figure 3-11 presents two types of data. One type of data is the range between the aircraft and balloon as derived from the radar data during the experiment. The second type of data indicates regions during which all or none of the desired data were acquired; in particular, those regions wherein the aircraft receiver could not achieve or maintain lock and those regions wherein radar data was not provided. The regions wherein no radar data was available are evident by the gaps in the aircraft to balloon range curve. The regions during which the receiver was not in lock are indicated by the cross-hatched intervals.

Significant periods of time during which the aircraft receiver was not in lock are evident in Figure 3-11. There are two different types of these gaps which should be noted. One type of data gap corresponds to those time intervals between the planned flight segments. These regions correspond to periods of aircraft maneuvering wherein neither radar data nor aircraft receiver lock was anticipated or planned.

The second type of data gap (loss of lock) occurs during the planned test period of nearly constant range. There are regions wherein external interference to the system was evident.

However, the duration of these periods is being magnified by the equipment which automatically enters a two-minute search mode should a momentary signal drop out occur. As noted in Section 2.2, this problem has been significantly alleviated by modifications to inhibit immediate entry into a search mode as well as a speed up in the search process itself.

4. EVALUATION OF EXPERIMENTAL DATA

The experimental data pertaining to the radar supported flight of 13/14 September 1971 has been evaluated. The intent of this evaluation is to determine ranging accuracy, error rate experienced by the 1200 bps and 600 bps data, and voice intelligibility. The lack of radar support for the flight of 17 September precludes the use of this data for ranging evaluation.

The presence of interference in the balloon-aircraft experimental data is indicated repeatedly in the ensuing evaluations. Unfortunately, the type of data gathered during the experiment does not permit anything more concrete than speculation as to its source, magnitude, and time dependence.

4.1 Carrier-to-Noise Ratio and High-Rate Data Error

One of the primary objectives of the experiment is to evaluate the performance of the 1200 bps data channel. This was achieved by means of a time-correlated measurement of bit error rate, and by comparing measured error distributions to theoretical performance for the corresponding levels of carrier-to-noise ratio measured, for the different flight segments.

The carrier-to-noise ratio measurements of the received signal were obtained by measuring the rms voltage at the "in-phase" and "out-of-phase" detector sections of the transceiver's Costas type demodulator for the 1200 bps data channel. When the Costas tracking loop is in lock for a DCPSK signal in the presence of Gaussian noise, the in-phase section contains signal-plus-noise, whereas the out-of-phase section contains only noise. The ratio of the rms voltage at the in-phase section to rms voltage from the out-of-phase section is then a direct indication of the received carrier-to-noise ratio. Because there is a fixed power relationship set at the ground station between the voice, data and surveillance channels, the carrier-to-noise ratio, C/N, for each of these channels can readily be computed from the 1200 bps data channel. The readout of C/N from the transceiver's modem unit was calibrated in the laboratory using all three modulated carriers with added white noise.

The instrumentation employed for measuring rms voltage in the Costas loop had a time constant on the order of one second. Such a long time constant, although smoothing out noise variations, precludes detection of rapid carrier-to-noise changes. In this regard, it should be emphasized that the calibration of the C/N was based only upon direct carrier and Gaussian type noise being present. With interference present the values obtained for the signal carrier-to-noise ratio would be in error, and evidence of such interference was noted.

Because the power radiated from the balloon could not be varied, the C/N level received by the transceiver was adjusted by a variable step attenuator at the transceiver's receiver input port. If the predominant source of noise was receiver noise, then this method could be used to establish a given C/N level such as 49 dB-Hz.

However, during all 6-degree medium-gain antenna flights, the received C/N was below 49 dB-Hz. This indicated that the C/N was not being established by receiver noise, but by external interference. Using the high-gain antenna, the desired 49 dB-Hz could be established. However, during some flight sequences, C/N could not be maintained at a given fixed level.

To correlate measured carrier-to-noise with bit error probability, carrier-to-noise level as recorded on the aircraft was used. Data were taken at 1-minute intervals and have been plotted vs time, as shown in Figures 4-1 through 4-6. Similarly, the recording of bit errors as they occurred in time at the ground station was used to determine the bit error rate during the 1-minute intervals, about the points of measured carrier-to-noise density; these data are also shown in Figures 4-1 through 4-6.

Figures 4-7 through 4-10 provide a direct comparison between theoretical and experimental performance. Figures 4-7 through 4-10 show a comparison of actual and theoretical bit error distributions based upon the statistical distribution of received carrier-to-noise density in the high-rate data channel. Each

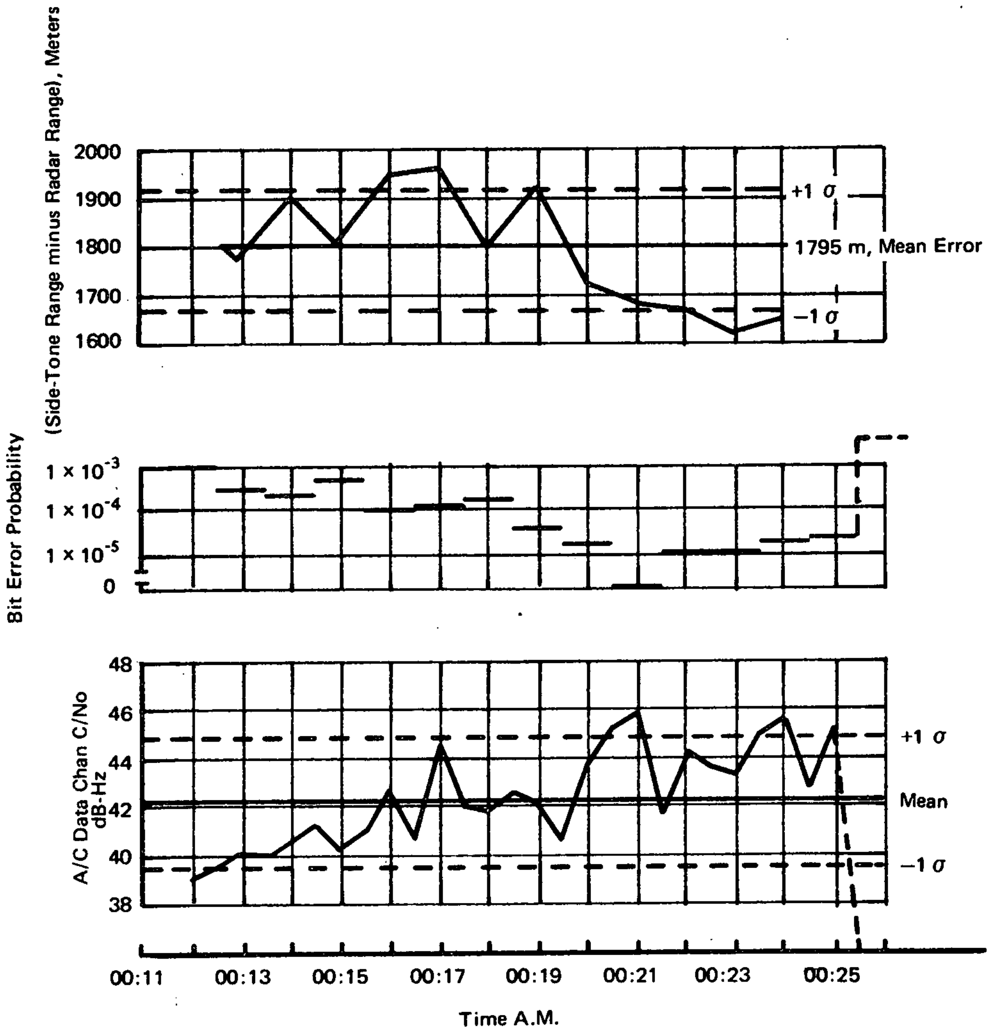


FIGURE 4-1. FLIGHT SEGMENT 1

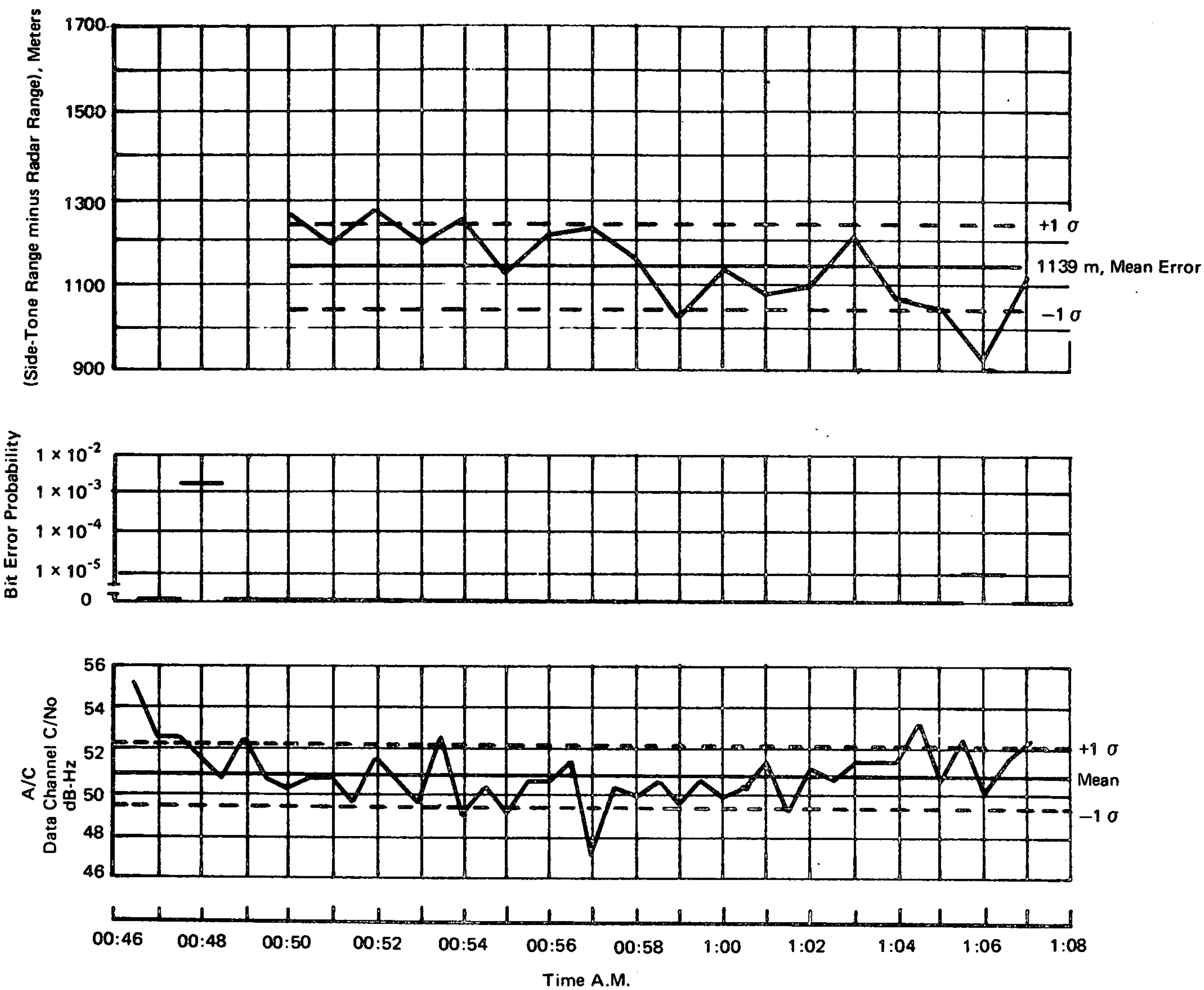


FIGURE 4-2. FLIGHT SEGMENT 2

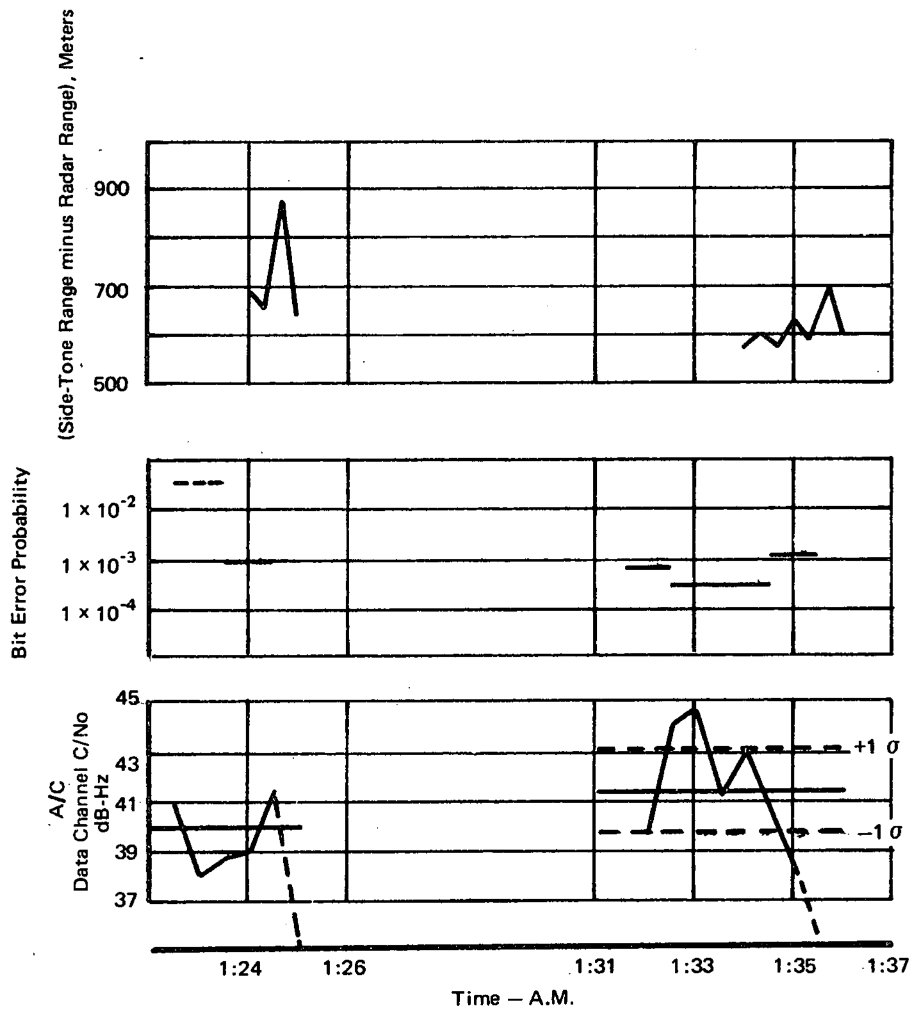


FIGURE 4-3. FLIGHT SEGMENT 3

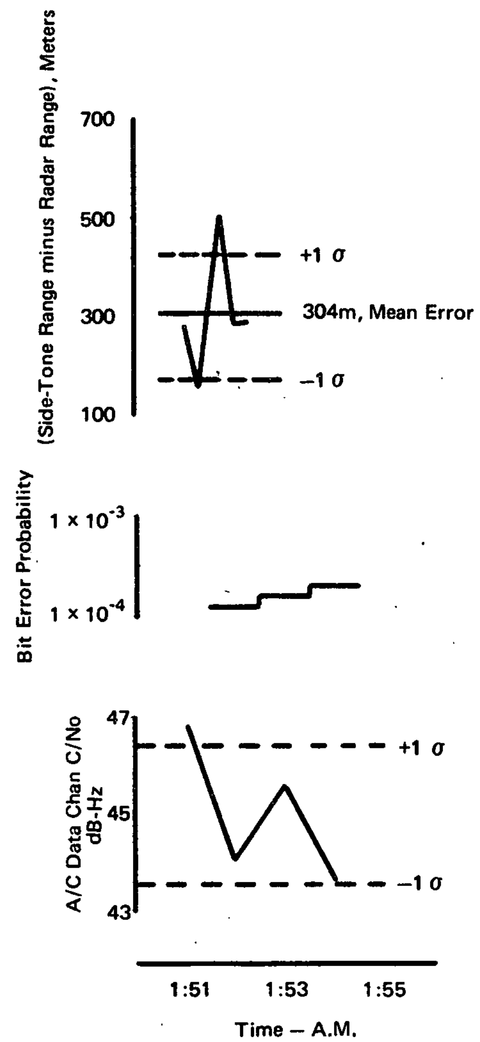


FIGURE 4-4. FLIGHT SEGMENT 4

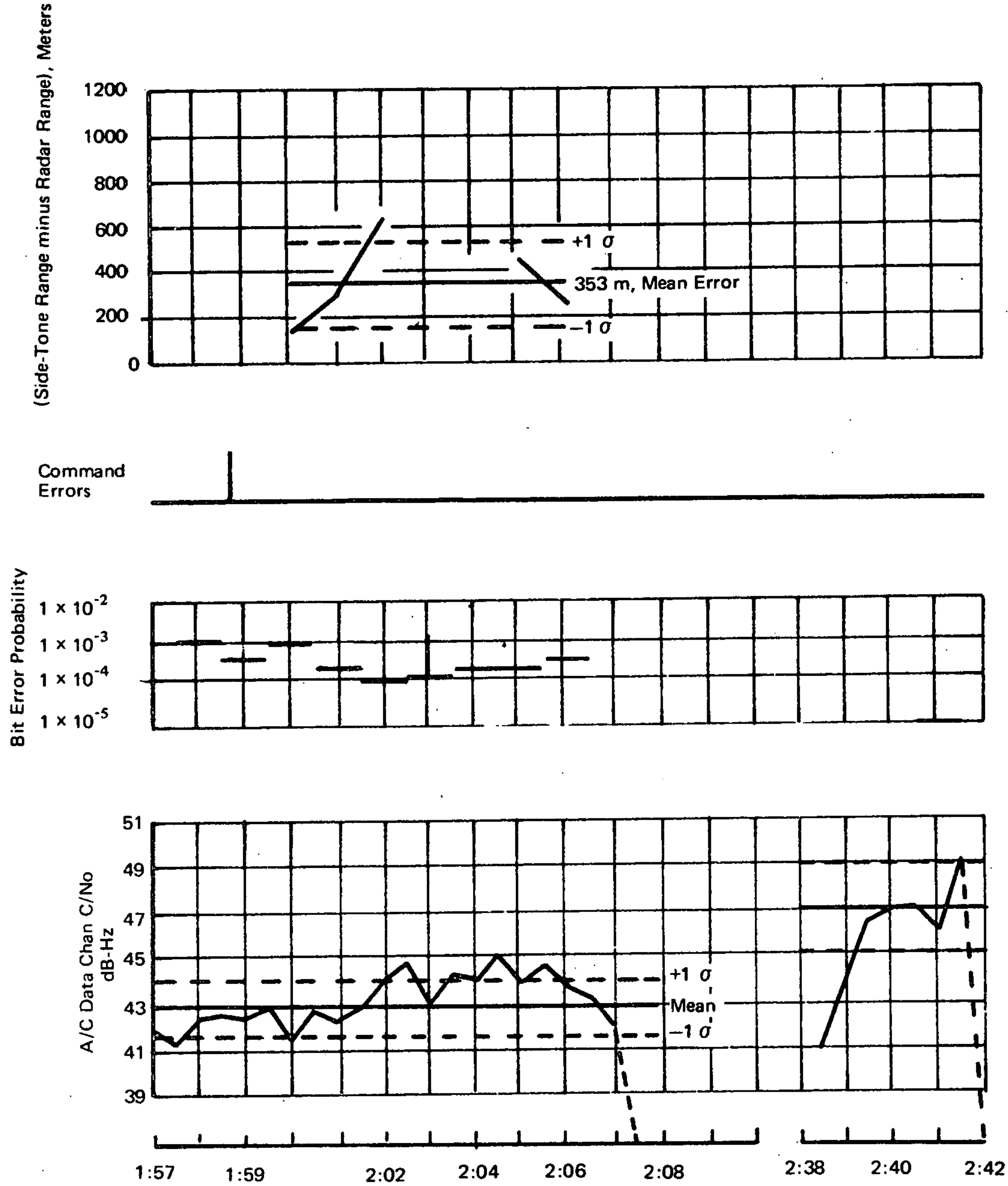


FIGURE 4-5. FLIGHT SEGMENT 5

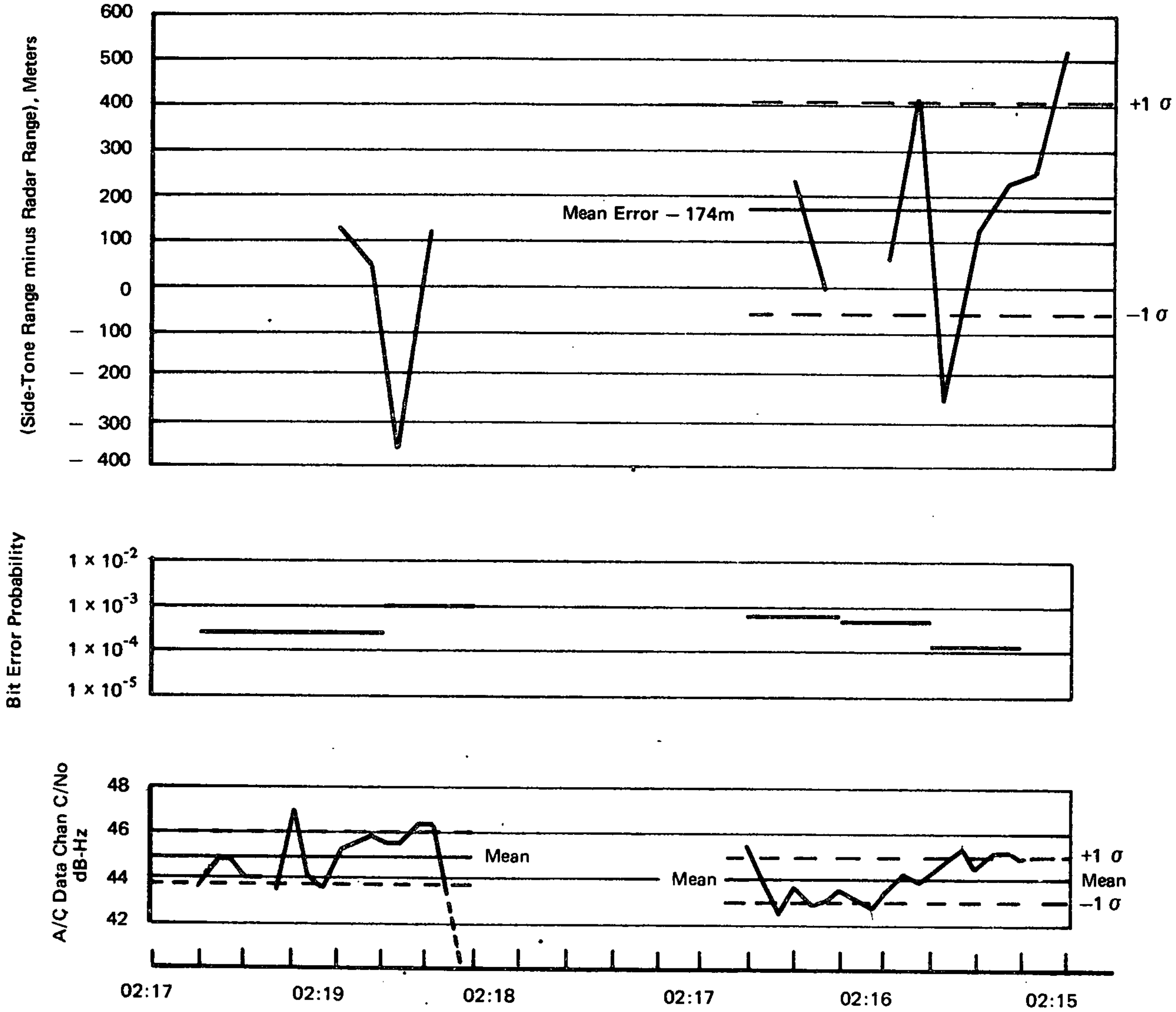


FIGURE 4-6. FLIGHT SEGMENT 6

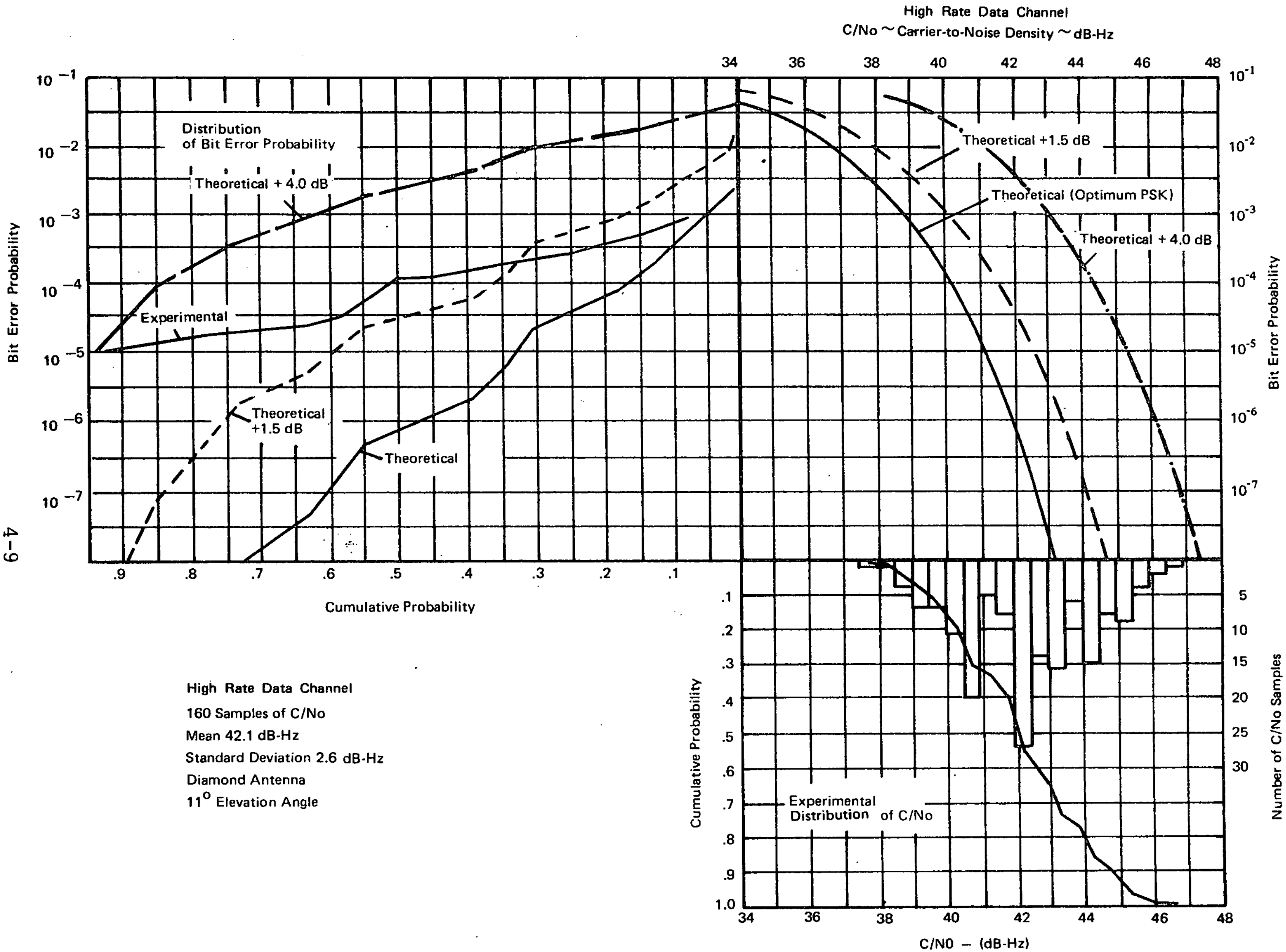


FIGURE 4-7. EXPERIMENTAL/THEORETICAL BIT ERRORS FOR FLIGHT SEGMENT 1

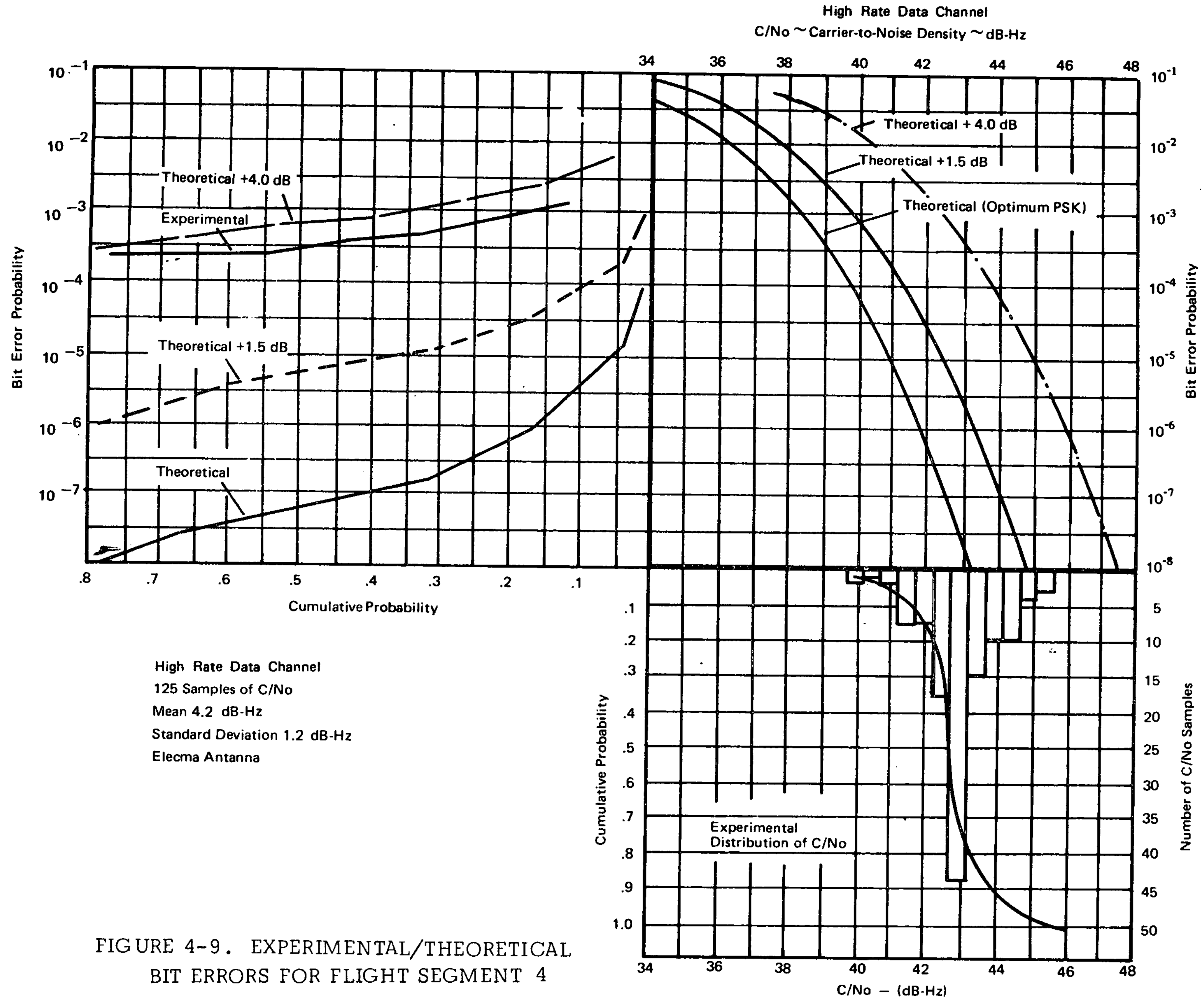


FIGURE 4-9. EXPERIMENTAL/THEORETICAL BIT ERRORS FOR FLIGHT SEGMENT 4

249 Samples of C/No
Mean 50.8 dB-Hz
Standard Deviation 1.4 dB-Hz
Elecma Antenna
High-Rate-Data Channel
No Experimental Bit Errors Encountered

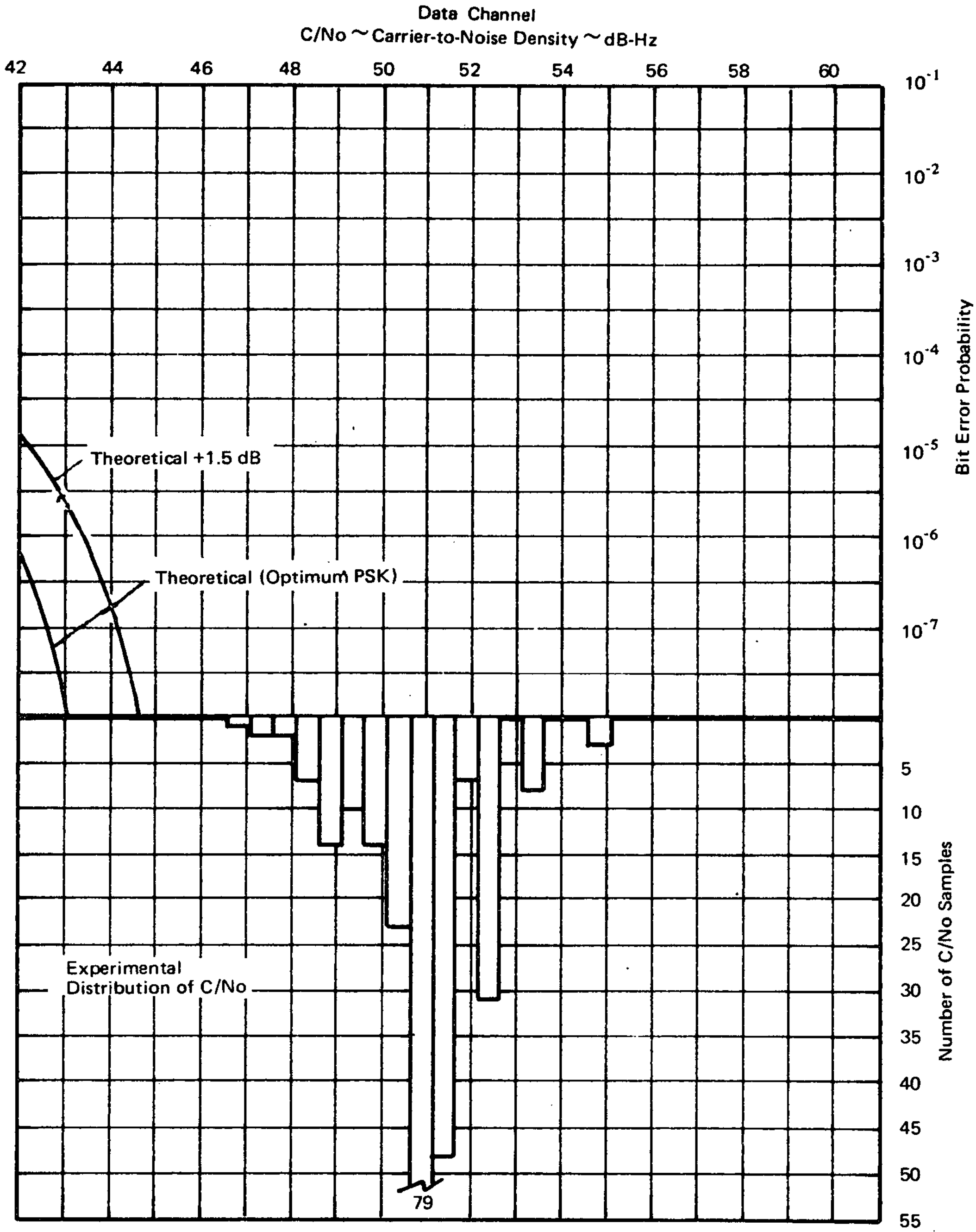


FIGURE 4-8. EXPERIMENTAL/THEORETICAL BIT ERRORS FOR FLIGHT SEGMENT 2

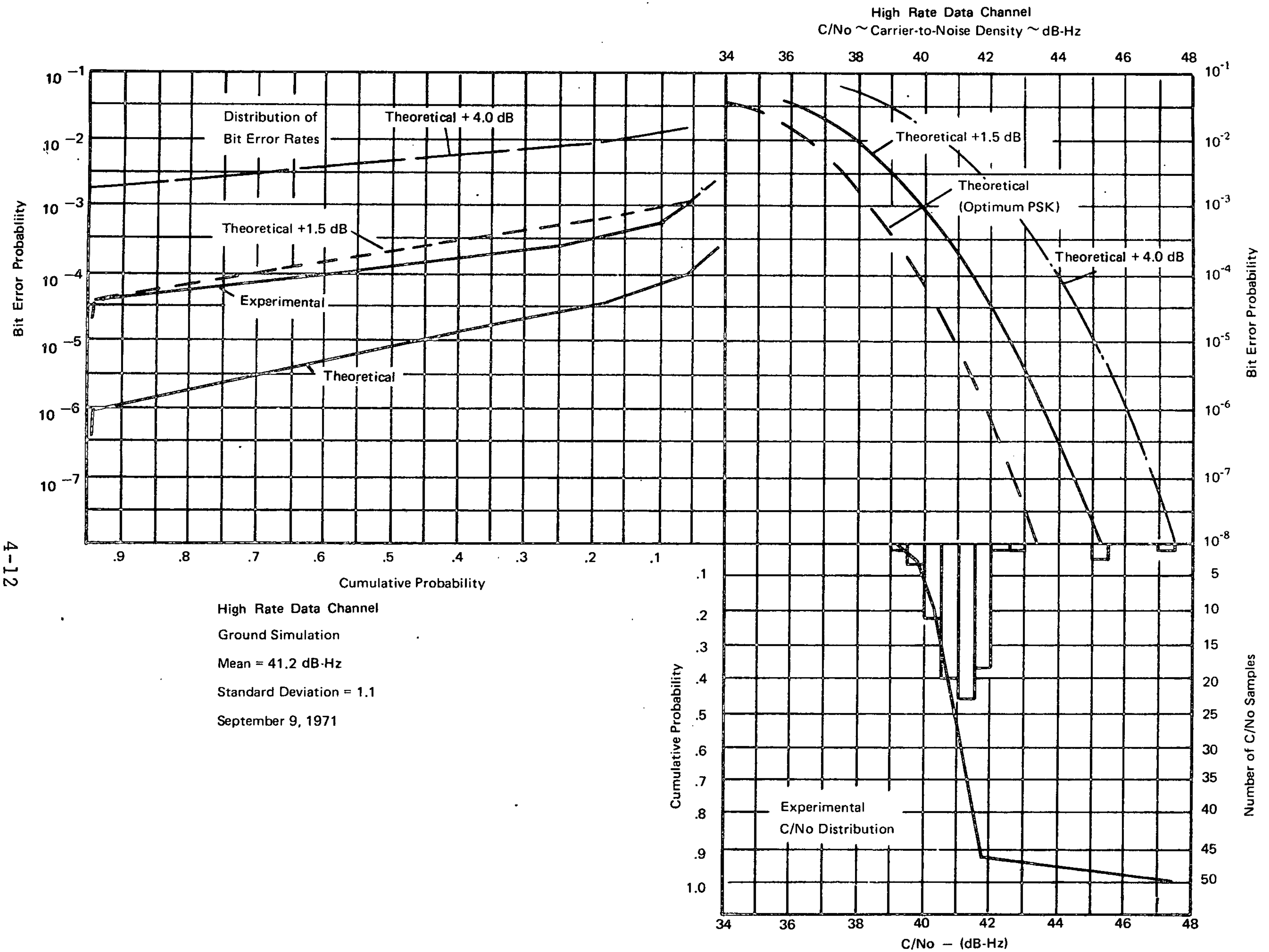


FIGURE 4-10. EXPERIMENTAL/THEORETICAL BIT ERRORS FOR GROUND TEST

of these figures consist of three graphs - (1) a histogram and cumulative distribution of carrier-to-noise samples, (2) the variation of bit error probability with carrier-to-noise density for optimum PSK signaling and for degradations of 4 dB and 1.5 dB, and (3) a comparison graph, wherein the cumulative distribution of bit error probabilities derived from the cumulative distribution of C/N samples is compared with experimentally observed distributions of bit error probabilities. Note in the data shown in Figure 4-8, the third comparison-graph does not appear because no bit errors were observed during this flight period. A numerical example will aid in the explanation of these figures.

In the lower right-hand portion of Figure 4-7, the histogram and resulting cumulative distribution of C/N samples is shown. In this case, approximately 50% of these samples were lower than 42 dB-Hz and 90% of the samples lie between 39 and 45 dB-Hz.

The upper right-hand portion of Figure 4-7 presents the theoretical relationship between C/N and bit error probability for two conditions-(1) optimum PSK signaling and (2), optimum PSK signaling with a degradation of 1.5 dB and 4 dB. Combining theoretical curves with the experimental distribution of C/N permits determination of the theoretical distribution of bit error probability shown in the upper left hand graph. For example, at a C/N of 42 dB-Hz, assuming optimum PSK performance, a bit error probability of about 10^{-6} would be anticipated. From the distribution of C/N samples, 50% of the samples yielded C/N higher than 42 dB-Hz. This would be anticipated because of the high received carrier-to-noise level. Therefore, the theoretical, distribution of bit error probability shows that the error probability should be less than 10^{-6} with a probability of $\frac{1}{2}$.

The experimental distributions of bit error probability noted in the upper left hand graphs were obtained by taking 1-minute intervals during each flight segment and determining bit error probabilities from the data. These samples of bit error probabilities were then transformed to the cumulative distributions. For example, in Figure 4-7, probability of bit error being less than 10^{-4} is about $\frac{1}{2}$.

Two aspects of the data should be discussed. First, the error-rate data acquired from the ground simulation test (Figure 4-10) perhaps without the interference encountered during flight, shows a variation of error rate that is comparable to theoretical. Secondly, if the interference is always present and related to the carrier(i.e., multipath interference), then the carrier-to-interference ratio must be relatively low as evidenced by the lack of bit errors during the high carrier-to-noise data acquired during flight segment 2 (Figure 4-8).

4.2 Side-Tone Ranging

The measurement of range between the aircraft and satellite is accomplished by measuring the transit time of a tone transmitted from the ground station through the balloon transponder to the aircraft transceiver, and returning by the same route. This time is determined by referencing the returning phase of either of the two tones to the phase of the transmitted tone, and then subtracting the fixed phase range shifts caused by the equipment through which the signals pass.

Figure 4-11 is a diagram of the path of a range tone from ground station to aircraft to ground station. The primary delays are:

T_1 = ground station transmitter

T_2 = ground station to balloon transponder

T_3 = balloon transponder (UHF to L-band)

T_4 = balloon to aircraft

T_5 = aircraft to transceiver

T_6 = aircraft to balloon

T_7 = balloon transponder (L-band to UHF)

T_8 = balloon to ground station

T_9 = ground station receiver.

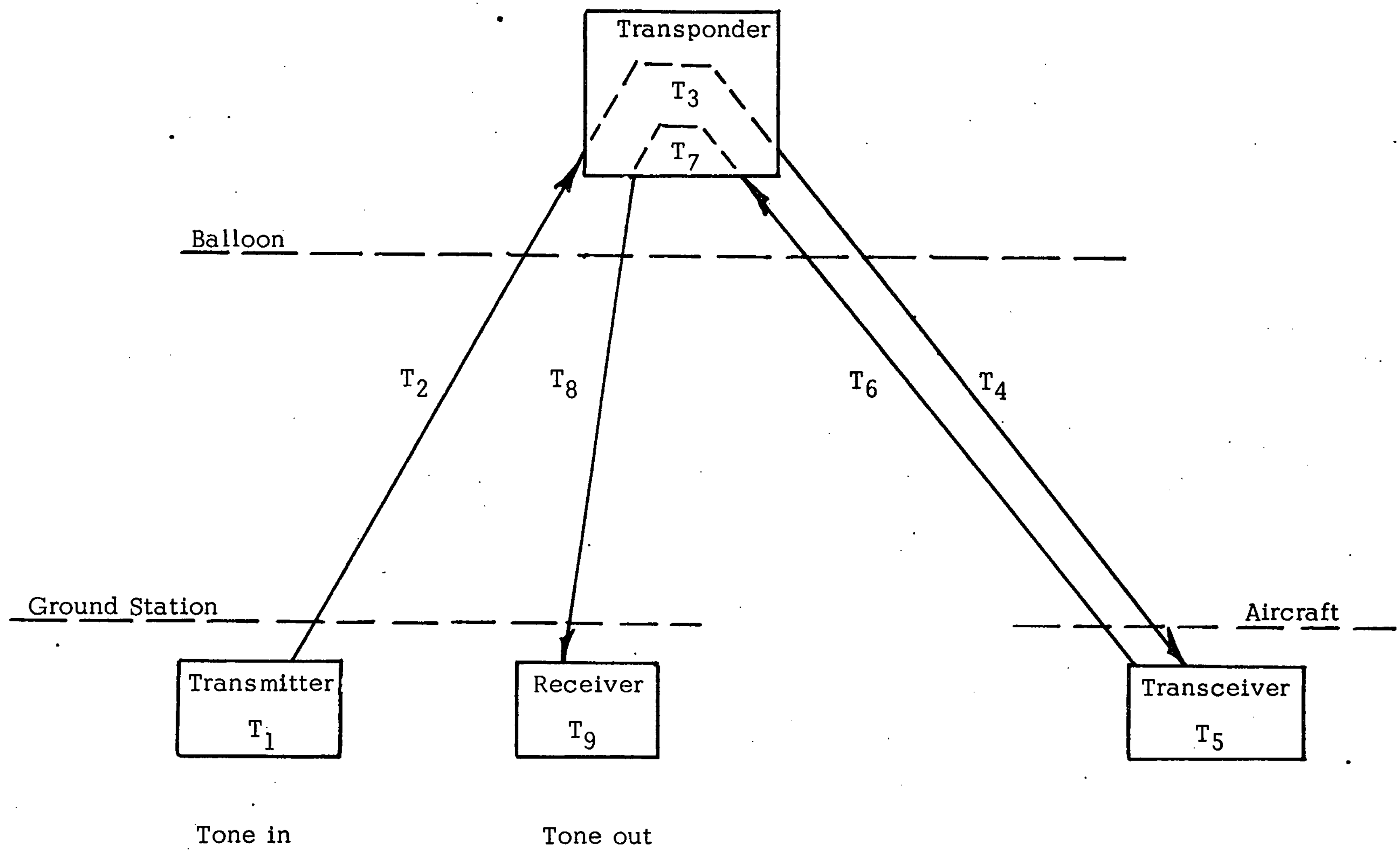


FIGURE 4-11. TONE PATH TIME DELAY DIAGRAM

During system calibration the sum of the fixed time delays was measured as a single parameter:

$$T_F = T_1 + T_3 + T_5 + T_7 + T_9$$

Also

$$T_2 = T_8 = T_{GB}$$

$$T_4 = T_6 = T_{AB}$$

so that

$$T_{total} = T_F + (2T_{GB} + 2T_{AB}) = \text{total time delay (between "Tone In" to "Tone Out" points, Figure 4-11).}$$

and

$$T_{GA} = (T_{total} - T_F)/2 = T_{GB} + T_{AB}$$

= time delay from ground station to aircraft via the balloon.

then

$$R_{GA} = (C/2)(T_{total} - T_F)$$

$$= \frac{C}{4\pi f} (2\pi n + \theta - \theta_F)$$

where

R_{GA} = range from ground station to aircraft via the balloon

C = velocity of light

n = an integer number of tone frequency wavelengths

θ = tone phase shift in radians

f = tone frequency, Hz

θ_F = fixed delay (T_F) expressed as phase shift

The value of n was determined as the lowest integer value of $f R_{GA}/C$, where R_{GA} is derived from the radar data.

The value of θ_F, which is a function of tone frequency, number of tones transmitted, tone mode (CW or pulse) and total carrier-to-noise density was measured during system calibration.

Estimation of the precision and accuracy of these tone ranging measurements is accomplished by comparison of these data with time correlated data acquired from two ground radars. One of these radars provided aircraft position coordinates while the other radar provided balloon position. Although the data are range, azimuth and elevation angles relative to each radar site, knowledge of the geographic coordinates of these sites, and the ground station permit determination of the desired ground station-to-balloon-to-aircraft range (see Appendix A).

The results of these radar and side-tone range comparisons were previously presented in Figures 4-1 through 4-6 as a function of time during the five flight segments. This presentation permits an evaluation of the changes in tone ranging precision and accuracy with carrier-to-noise density variation. However, while carrier-to-noise correlation is not evident, each Figure does indicate a decreasing bias error as time increases.

A better presentation of this time-dependent bias is given in Figure 4-12. Here, the difference between side-tone range measurements and the radar-determined ranges are shown on a collapsed time scale, corresponding to the entire flight of 13/14 September.

Figure 4-12 shows the precision of the tone ranging system is on the order of a few hundred meters at a range of 250 kilometers and of equal importance, this precision is maintained throughout regions wherein carrier-to-noise density was marginal and where performance of the high-rate data channel was poor.

The presentation of Figure 4-12 also clearly indicates a long term "warm-up" phenomena was present during the flight. A bias of nearly 2000 meters is initially present and this decays monotonically during successive

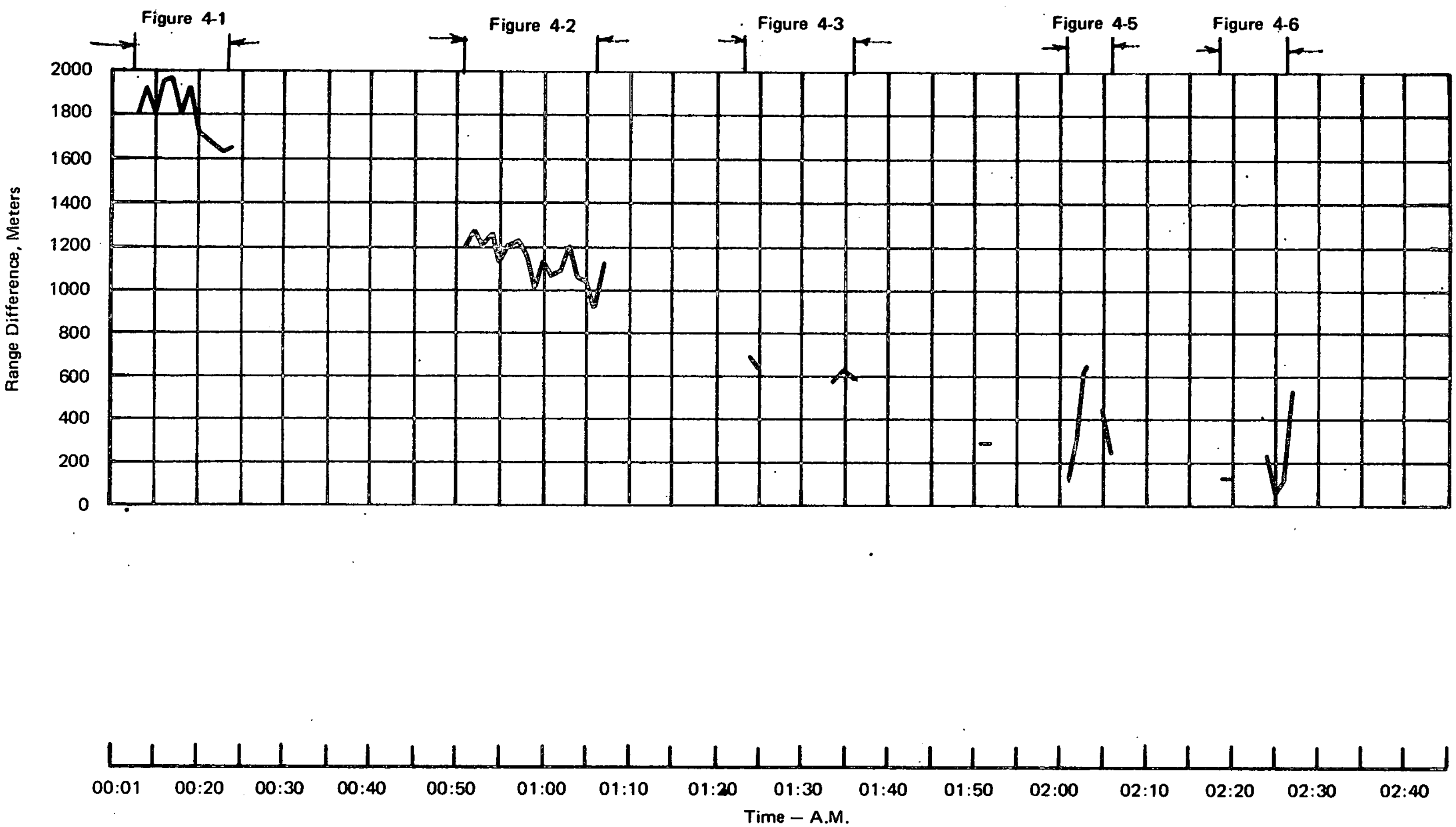


FIGURE 4-12. RANGE DIFFERENCE VS TIME-SEPTEMBER 13-14,1971

flight segments to a value of several hundred meters without significant change in the precision or short term fluctuation of the measurements about the bias. No assignable reason was found for this behavior except that the nearly exponential shape of the data in Figure 4-12 suggests some type of equipment warm-up problem may have been present.

Another aspect of the tone ranging channel is that the mode of operation apparently does not influence the measurements. In particular, the precision of the CW tone ranging measurements is entirely comparable to the precision of the pulse measurements.

The remaining data available to evaluate the tone ranging system is shown in Figure 4-13 where the tone ranging measurements are compared with estimated range to the transceiver when located atop Pic-Di-Midi mountain. Because the actual range in this case is not precisely known, the bias of these data can not be viewed with confidence. However, the precision of the measurements can be seen to be comparable to those experienced in flight and there is no evidence of a time dependent basis.

A numerical summary of the performance of the tone ranging measurements is provided in Table 4.2 for the five flight segments. These data provide statistical measures of performance such as mean errors and standard deviations. For example, during flight segment 1, the average range difference (Δ R) between side-tone and radar range was found to be 1795 meters and the standard deviation of these differences is 122 meters. These errors were derived, as noted in Table 4-2, from both the 7350 and 8575 Hertz tones when in the CW mode of transmission.

4.3 Voice Intelligibility

During the ground test of September 9, 1971 and the subsequent flight test of September 13, 14, 1971, specially prepared tapes containing modified rhyme test words, phonetically balanced test words and articulation index signals were transmitted from the ground to the aircraft where they were

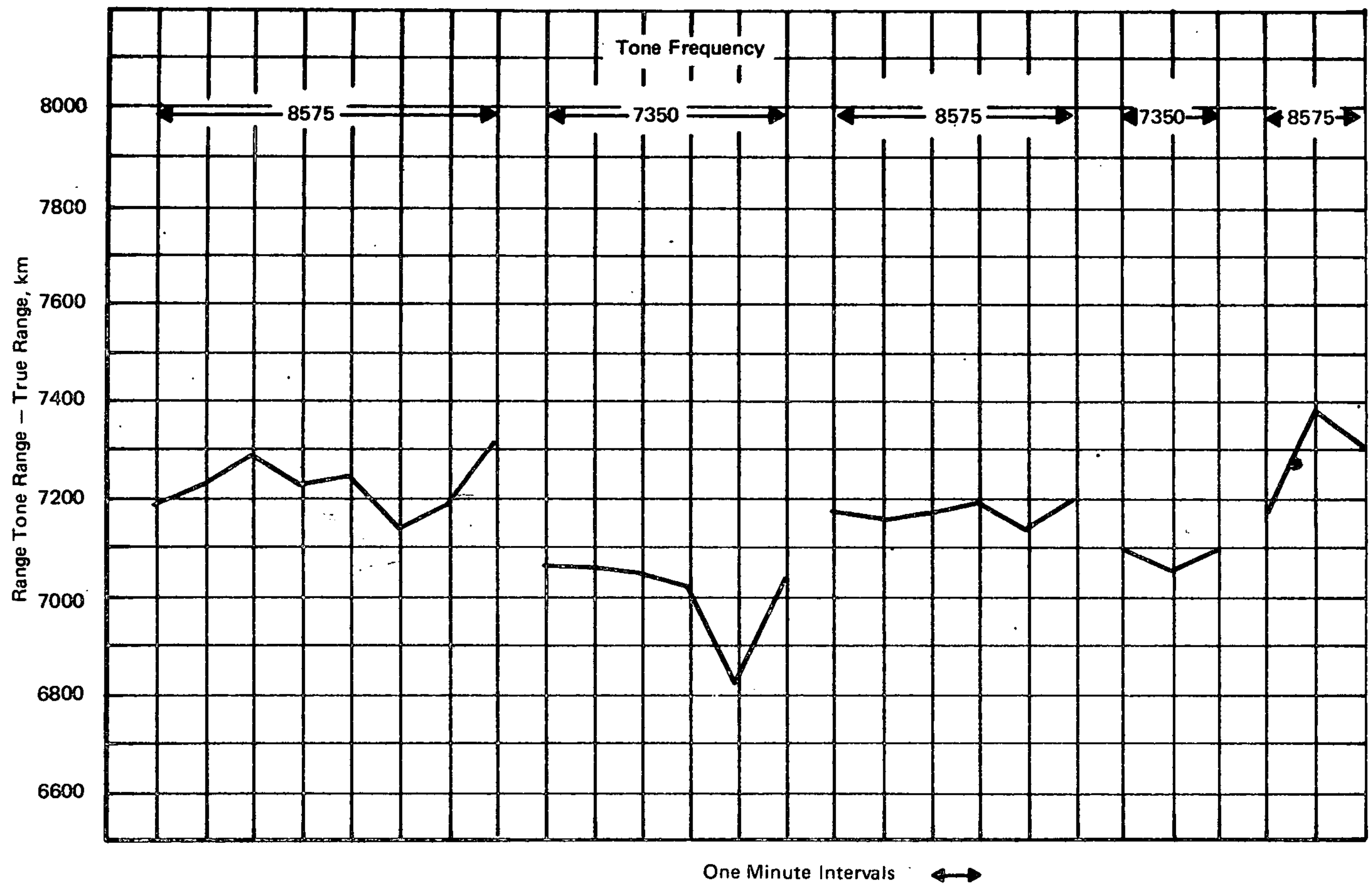


FIGURE 4-13. RANGE DIFFERENCE VS TIME, GROUND TEST
SEPTEMBER 9, 1971

TABLE 4-2

STATISTICS OF RANGE DIFFERENCES

Flight Segment	Mean $\Delta R \sim m$	Std Dev $\Delta R \sim m$	Tone Frequency	Tone Mode
1	1795	122	Both	CW
2	1139	96	Both	CW
3	713	109	8575	CW
	605	45	8575	CW
4	304	128	7350	Pulse
	352	191	8575	
5	-14	234	7350	Pulse
	174	234	7350	

recorded for later evaluation. During the flight of September 17, 1971, the full duplex voice channel was employed for message relay between the aircraft and the ground. For all three aircraft voice channels, excellent (in an ATC context) communication was maintained and all messages were received and executed with no repeat requested.

During the flight of September 13- 14, 1971 two hours of recorded data were obtained. It should be noted that because of the higher power assigned to the voice channel (46 dB-Hz) and the extremely low threshold level of the FM voice demodulator, (approximately 35 dB-Hz) the voice channel maintained communications even when the data and surveillance channels lost lock.

Because of the limited test facilities, only the modified rhyme test words were evaluated for each flight sequence. The articulation index (AI) was not obtained because the SCIM equipment at FAA/NAFEC was not functioning and the program for computerized Articulation Index Evaluation has not been completely debugged and verified. Reference F provides a detailed description of the Modified Rhyme Test. The Phonetically Balanced words and typical air traffic control messages were not analyzed because of lack of time.

To provide a broad test base, several sets of MRT words were used with different speakers. The use of different speakers and sets of words result in intelligibility scores having different sensitivities for different received carrier to noise levels.

Voice intelligibility analyses were conducted in the following manner. The recorded test tapes containing modified rhyme test (MRT) words were played to a jury of male listeners and the percentages of words correctly identified by the jury was used to compute the percent intelligibility. Table 4-3 summarizes these results.

These tests were conducted at two Prince Georges County Maryland Schools under the supervision of Charles Thompson, Bowie High School, and Mary Kiefer and Jack Renner, Du Val High School. Edward Turner, Director of Staff Development for Prince Georges County Public Schools, helped plan Goddard's use of the school facilities and arranged for teacher involvement. Richard Crone of Goddard's Educational Programs Office coordinated the joint effort between GSFC and Prince Georges County Public School Systems.

Table 4-3 which summarizes the flight sequence, time of flight sequence, mean C/N and mean intelligibility of word sets, shows that for most flight sequences good-to-excellent voice reception was obtained. Intelligibility during the flight sequences varied from 95.6 percent at high carrier-to-noise levels to 61.6 percent at poor carrier-to-noise levels. Out of 24 tests sets observed for the entire flight only 2 test sets had missing words. Fading was not evident in the observed communicated speech, only a severe increase in the noise level was noted when the voice channel operated poorly. However, short duration noise pulses were observed.

A further evaluation of the voice channel recording was performed to gain further insight regarding the interference during the 13-14 September, 1971 flight. In particular, an analysis was made of the output noise from the voice channel demodulator when receiving unmodulated carrier. Because the input to the voice channel demodulator is hard limited, the demodulation noise output is a measure of the input C/N.

Figure 4-14 is a typical plot of the noise as a function of time for the ground simulation test. It is noted that the periodic variation of the rms noise is in the order of 10 seconds and the peak-to-peak variation is about ± 1.1 dB. Figure 4-15 is a typical plot of the noise as a function of time prior to loss of lock. The peak-to-peak variation is about ± 2.0 dB.

C.2

TABLE 4-3

INTELLIGIBILITY TEST RESULTS

Time	Flight Path	Test Type	Word List	Intel. Mean	Intel. Var	Voice Channel Mean C/N_0
23:25:32	P2-P1	SCIM				47.5
23:28:19	P2-P1	MRT	B-1	Dropouts		
23:30:40	P2-P1	MRT	C-3	92.18	$\pm$2.88	
23:35:54	P2-P1	SCIM				
23:40:09	P2-P1	MRT	F-3	76.54	$\pm$5.90	
23:42:26	P2-P1	MRT	F-4	82.90	$\pm$4.54	
23:50:30	P2-P1	SCIM				47.5
00:01:38	P1-P2	SCIM				46.2
00:06:00	P1-P2	MRT	B-1	Dropouts		
00:08:15	P1-P2	MRT	C-3	61.63	$\pm$8.64	
00:13:30	P1-P2	SCIM				
00:17:45	P1-P2	MRT	F-3	75.8	$\pm$9.05	
00:20:00	P1-P2	MRT	F-4	78.3	$\pm$4.6	46.2
00:44:03	P4-P3	SCIM				54.9
00:48:22	P4-P3	MRT	B-1	91.7	$\pm$3.83	
00:50:26	P4-P3	MRT	C-3	95.6	$\pm$3.47	
00:55:55	P4-P3	SCIM				
01:00:10	P4-P3	MRT	F-3	90.9	$\pm$4.30	
01:02:25	P4-P3	MRT	F-4	92.4	$\pm$4.36	54.9
01:13:22	P3-P4	SCIM				54.7
01:17:43	P3-P4	MRT	B-1	90.4	$\pm$2.30	
01:20:00	P3-P4	MRT	C-3	92.4	$\pm$3.76	
01:25:18	P3-P4	SCIM				
01:29:32	P3-P4	MRT	F-3	86.4	$\pm$6.42	
01:31:50	P3-P4	MRT	F-4	90.8	$\pm$4.66	
01:43:55	P3-P4	SCIM				54.7
01:48:14	P4-P3	MRT	B-1	92.4	$\pm$4.16	49.1
01:50:13	P4-P3	MRT	C-3	92.4	$\pm$4.16	
01:55:50	P4-P3	SCIM				
02:00:07	P4-P3	MRT	F-3	74.66		
02:02:22	P4-P3	MRT	F-4	80.12		49.1
02:17:37	P3-P4	SCIM				48.5
02:21:50	P3-P4	MRT	B-1	Not recorded		48.5
02:24:	P3-P4	MRT	C-3	Not recorded		48.5
02:30:50	P3-P4	SCIM				56.8
02:35:00	P3-P4	MRT	F-3	80.83		
02:37:20	P3-P4	MRT	F-4	89.33		
02:45:50	P4-Bor	SCIM				
02:50:12	P4-Bor	MRT	B-1	88.16		
02:52:25	P4-Bor	MRT	C-3	94.50		56.8

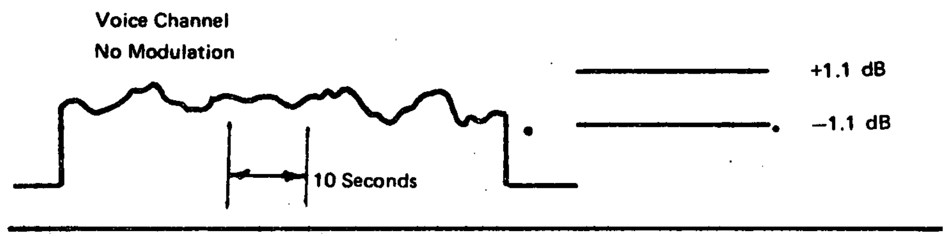


FIGURE 4-14. GROUND TEST-SEPT. 9, 1971
RMS NOISE OUTPUT OF VOICE CHANNEL

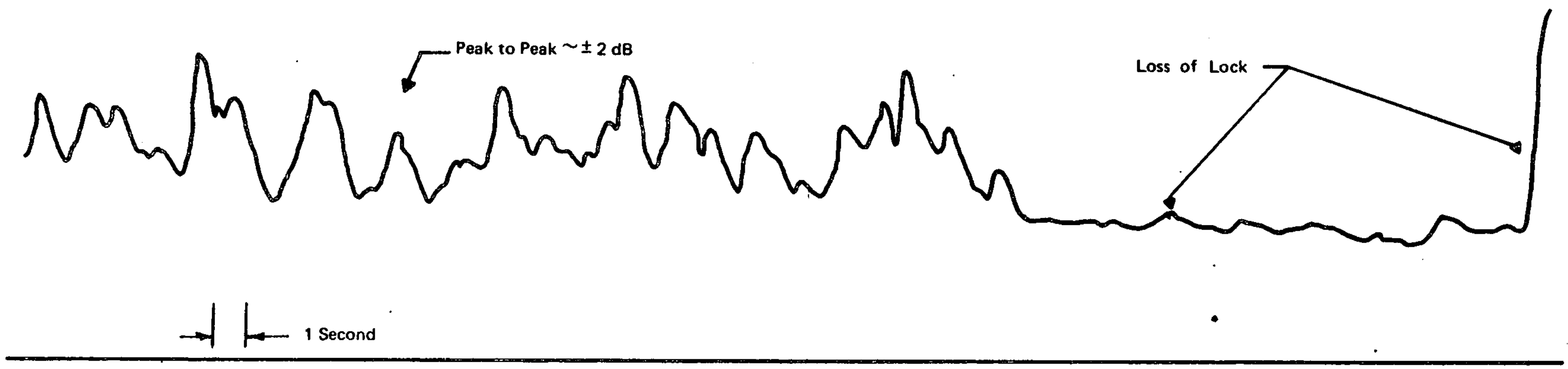


FIGURE 4-15. NASA FLIGHT—SEPT. 13, 1971
RMS NOISE OUTPUT OF VOICE CHANNEL

Figure 4-16 is a plot of the noise as a function of time when impulse spikes of magnitude 6.5 dB, pulse duration in the order of 5 to 10 seconds were recorded. These spikes occurred randomly. An investigation was made to determine if these spikes were unique to the NASA equipments by reviewing the ESRO equipment voice channel outputs. Figures 4-17 and 4-18 are plots or rms test tone pulses as a function of time for the ESRO voice communications equipment. Figure 4-17 shows for a typical flight the test tone had a peak-to-peak variation of $\pm$ 1.4 dB for the narrow band FM voice channel (which for NBFM is directly related to carrier variation). Figure 4-18 shows for a typical flight, the test tone is severely attenuated by spikes as great as 14 decibels. Thus, the ESRO data confirms that the spikes and C/No variations observed were external to the NASA equipment and that the carrier-to-noise variations observed by NASA were probably carrier level variations.

4.4 Command/Control Data Channel

The low data rate channel was used during the experiment to provide transceiver timing command and control. Throughout all flight segments, while the transceiver was in lock, all of these functions were performed satisfactorily except for the following instances of command errors.

At 1:34:02 of the 13-14 September, 1971 a false command was executed (i.e., appeared on status recording) which was immediately followed by a second command error in the next interrogation slot. Similarly, a third erroneous command was executed at 1:35:02. Considering a total in-lock test time of 56 minutes and therefore, a total of about 56 command slots, the error rate is obviously excessive even if the statistical base is small.

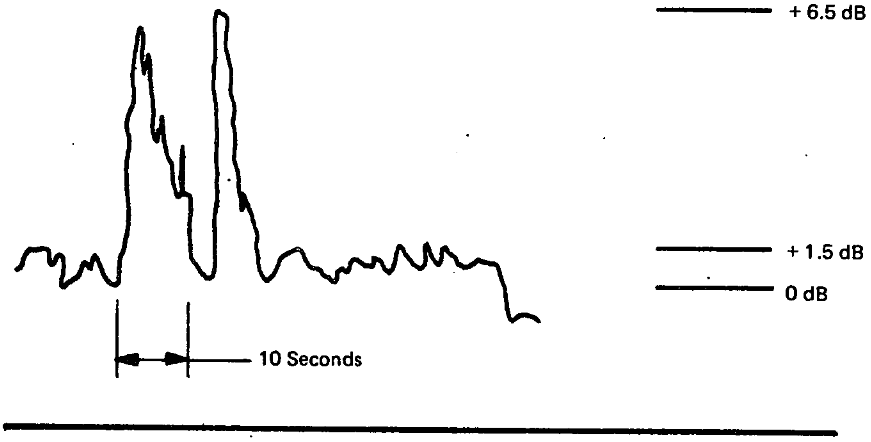


FIGURE 4-16. NASA FLIGHT—SEPT. 13, 1971
RMS OUTPUT OF VOICE CHANNEL

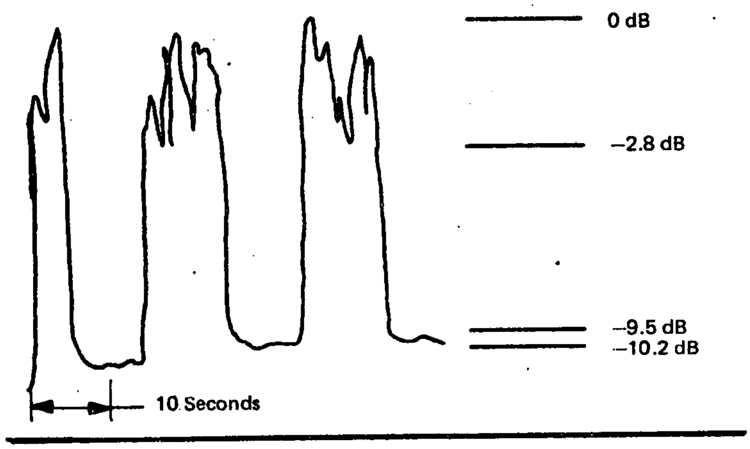


FIGURE 4-17. EUROPEAN FLIGHT
NBFM VOICE CHANNEL
RMS TT/N READOUT

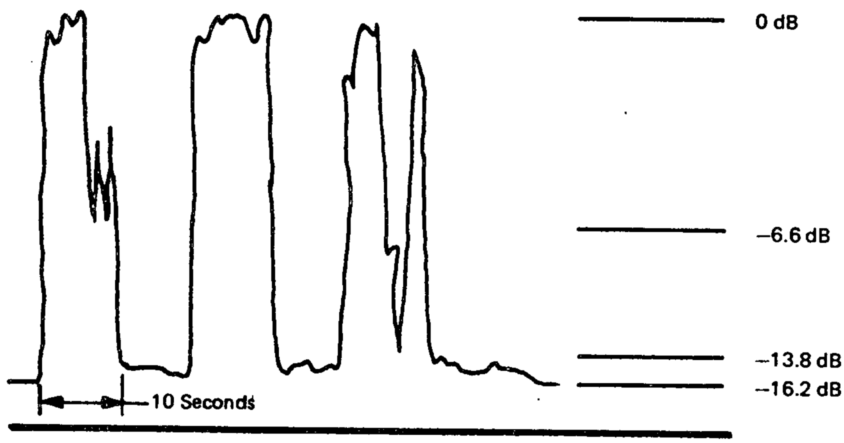


FIGURE 4-18. EUROPEAN FLIGHT
PDM VOICE CHANNEL
RMS TT/N READOUT

APPENDIX A

COORDINATE TRANSFORMATION OF RADAR DATA

In order to evaluate the tone ranging measurements during the experiment, the sum of the line-of-sight distances from the ground station to the balloon and from the balloon to the aircraft must be determined. This appendix briefly describes the computations leading to this sum as derived from the radar data provided.

The radar tracking during the balloon-aircraft experiment was performed by two separate radars. One of these radars was utilized to track the balloon and was located at Hourton, France. The other radar was located at Biscarrosse, France and provided aircraft tracking. Furthermore, the experimental ground station was located at Aire Sur Ladour—i.e., at a different location.

The geographic locations of the radars and ground stations are as follows:

- Balloon Radar @ Hourton
  $45^{\circ}8'8.65''$ north latitude
  $1^{\circ}9'59.71''$ west longitude
  -19.70 meters altitude

- Aircraft Radar @ Biscarrasse
  $44^{\circ}25'34.3''$ north latitude
  $1^{\circ}13'19.5''$ west longitude
  -20.28 meters altitude

- Ground Station @ Aire Sur Ladour
  $43^{\circ}42'25.33''$ north latitude
  $o^{\circ}14'56.75''$ west longitude
  99.76 meters altitude

Note altitudes are with respect to the international ellipsoid—hence the negative altitude for the radar sites.

The radar data were provided as range, azimuth, and elevation of the aircraft and balloon relative to the radar sites. Obtaining range from ground station-to-balloon-to-aircraft then, required the following manipulations. Note, the x,y,z axis systems employed are all right handed with the z axis parallel to local vertical. Furthermore, the proximity of the radars, ground station and aircraft-balloon coupled with the magnitudes of experimental errors anticipated, led to neglect of spherical earth effects.

The range from ground station to aircraft was calculated from the radar data by determining the coordinates of the aircraft and ground station relative to the aircraft racking radar, determining the coordinates of the balloon relative to the balloon tracking radar, and translating the origin of the second coordinate system to coincide with the first. With the radar located at R and the aircraft at A, the given data are range RA, azimuth angle θ_{AZ} and elevation angle θ_{EL}. Then the coordinates of the aircraft relative to the radar $(X_A Y_A Z_A)$ are

$$X_A = RA \cos\theta_{EL} \cos\theta_{AZ}$$

$$Y_A = RA \cos\theta_{EL} \sin\theta_{AZ}$$

$$Z_A = RA \cos\theta_{AZ} \sin\theta_{AZ}$$

The coordinates of the balloon $(X_B Y_B Z_B)$ are similarly found and a translation of coordinates is made to reference the aircraft and balloon to the same origin. Then the radar range from ground station to balloon (RR_{GB}) and the range from balloon to aircraft (RR_{BA}) are computed from:

$$RR_{GB} = (X_B - X_G)^2 + (Y_B - Y_G)^2 + (Z_B - Z_G)^2$$

$$RR_{BA} = (X_B - X_A)^2 + (Y_B - Y_A)^2 + (Z_B - Z_A)^2$$

and the signal path length from ground station to aircraft is

$$RR_{GA} = RR_{GB} + RR_{BA}$$

REFERENCES

A. Place Airborn Equipment, Detailed Design Review Agenda, Bell Aerospace Co., Report No. 6203-945004, August 1971.

B. The ATS-F and G Data Book, Goddard Space Flight Center, Greenbelt, Maryland, October 1971.

C. Place Ground Equipment Critical Design Review Report, Bell Aerospace Co., Report No. 6225-933003, September 1971.

D. Proposal for Equipment for A European Balloon Test, Bell Aerospace Co., Report No. 6302-953001, December 1970.

E. Balloon-Aircraft Ranging, Data and Voice Experiments, Test Plan.

F. Voice Coding and Intelligibility Testing for a Satellite Based Air Traffic Control System, Birch and Getzin, the Magnavox Co., April 1971.

G. Introduction to Statistical Analysis, Dixon and Massey, McGraw Hill, 1957.

H. Statistics in Research, Ostle, Iowa State University Press, 1963.

I. CRC Handbook of Tubler for Probability and Statistics, The Chemical Rubber Co., 1966.

J. PLACE Final Report, Clausen, Lerner, Rupp and Winter, Report No. 6225-95002, Bell Aerospace Co., June 1970.

K. Multichannel FSK and DPSK Reception with Three-Component Multipath, J. J. Jones, IEEE Transactions on Communication Technology, December 1968.

L. "NASA Balloon - Aircraft Ranging, Data and Voice Experiment," Sheldon Wishna, NASA Document X-752-71-212, Goddard Space Flight Center, Greenbelt, Maryland, 20771, July 1971.